Chapter 4
PROPOSED MINIMUM FLOWS AND LEVELS CRITERIA

The following sections present the Minimum Flows and Levels (MFL) criteria as required in Chapter 373, Florida Statutes for Lake Okeechobee, the three Water Conservation Areas (WCAs), the Holey Land and Rotenberger WMAs, the freshwater regions of Everglades National Park, and the Biscayne aquifer. Each section provides a summary of the technical relationships which were considered in defining significant harm for each water body and a detailed presentation of the proposed MFL criteria with supporting documentation.

For the purposes of this study, significant harm is defined as a loss of specific water resource functions resulting from a change in surface water or ground water hydrology that takes multiple years to recover from (see Chapter 1 for further discussion of the definition of significant harm).

LAKE OKEECHOBEE

Resource Functions

The following water resource functions were considered in the development of the proposed minimum water level criteria for Lake Okeechobee:

- Provide water that can be used to maintain water levels in coastal canals, meet human needs and protect the Biscayne aquifer against saltwater intrusion
- Supply water and provide water storage for the Everglades
- The lake is a regionally important ecosystem that provides fish and wildlife habitat and supports commercial and sport fisheries.
- Maintain navigation and recreational use

Additional factors that were considered included the need to supply water to areas other than the Everglades and the Biscayne aquifer, including the Caloosahatchee River, St. Lucie Canal, the Seminole Indian Tribe, and the Everglades Agricultural Area.

Technical Relationships Considered in Defining Significant Harm

Protection of the Coastal Aquifer

As part of the Central and Southern Florida (C&SF) Project, Lake Okeechobee plays a critical role as a source of fresh water to maintain coastal ground water levels which prevent saltwater intrusion of the Biscayne aquifer. During dry periods when freshwater supplies are depleted along the lower east coast of Florida, fresh water is discharged from interior storage areas such as Lake Okeechobee and, when available, the WCAs, to the coastal canal system. These water releases help maintain a freshwater head within the coastal ground water aquifer that prevents inland movement of the saltwater front. Saltwater intrusion can occur whenever water levels within local canals or the aquifer drop below the elevation needed to stabilize the adjacent saltwater front.

Historical records show that when lake levels fall below 11 ft NGVD, water shortage restrictions have been imposed along Florida’s lower east coast (Hall, 1991). **Figure 11** provides a summary of the relationship between lake stage and the amount of water that can be stored in the lake for delivery to lower east coast canals during dry periods. Historical data shows that when lake water levels reach 11 ft NGVD, these levels typically continue to decline rapidly, affecting the District’s ability to deliver water to coastal canals. Once water levels fall below 10.5 ft NGVD, the physical limitations of the lake’s primary outlet structures make it increasingly difficult to convey water from the lake to coastal canals. The 10.5 ft NGVD elevation generally represents the bottom of the conservation pool for water supply planning purposes. The District has established a water conservation policy (i.e., Supply-Side Management Plan) which applies a percentage reduction to water withdrawals below the seasonally varying water supply schedule.

Water Supply for Everglades National Park.

Shortly after Everglades National Park was created, it became apparent that it was not receiving sufficient freshwater flows during dry periods to maintain viable aquatic ecosystems and protect vegetation and wildlife from damaging fires. In 1970, Congress adopted Public Law 91-282, which provided a minimum water delivery schedule for Everglades National Park based on minimum monthly flow requirements. Later, it became apparent that this schedule resulted in unnatural volumes and timing of water flows discharged from the WCAs to western Shark River Slough. This altered flow regime caused failure of alligator nests, abandonment of wading bird rookeries, and alteration of wetland communities (NPS-SFRC, 1989). In 1984, this delivery schedule was replaced with a water delivery model called the Rainfall Plan, to provide a more natural timing of water deliveries to Everglades National Park (MacVicar, 1985; Neidrauer and Cooper, 1989). Using this approach, water is discharged into Everglades National Park during periods when rain falls within the upstream watershed. If no rainfall occurs, then no water is provided. This management method has helped maintain more natural cycles of wet and dry season flows to Everglades National Park and meet it's water needs during regional droughts. The Rainfall Plan has also helped to reestablish more natural hydroperiods and better overland flow to Shark River Slough (Light and Dineen, 1994). This plan is in effect today while other additional improvements are being evaluated, such as the Modified Water Deliveries to Everglades National Park Plan, and the C-111 South Dade Project.

Water deliveries from Lake Okeechobee to the Everglades are made pursuant to the District’s Best Management Practice (BMP) Make-Up Water rule, Part II of Chapter 40E-63, F.A.C. Deliveries under this rule are made consistent with a model that quantifies the amount of water to be replaced due to reduction of flow to the Everglades Protection

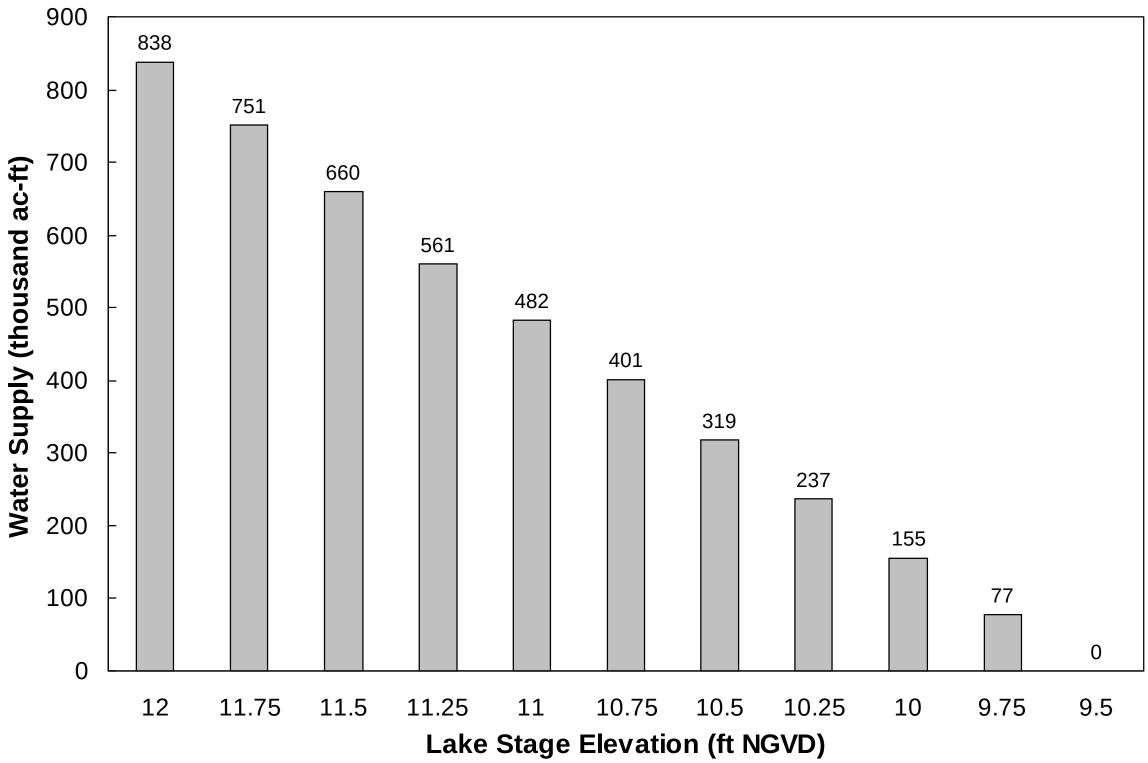

Figure 11. Amount of Water Available in Lake Okeechobee for Delivery to LEC Planning Area Canals at Various Stage Levels. Source: SFWMD data. Graph based on lake stage/ volume relationship.

Area resulting from implementation of BMPs within the EAA. Under extreme hydrologic conditions, such as when Lake Okeechobee levels are at the warning stage or lower, pursuant to the Supply-Side Management Plan, the rule provides the Governing Board with the authority to deviate from the delivery schedule. At this time, no approved plan for Everglades National Park deliveries during water shortage has been incorporated into the Supply-Side Management Plan. Such delivery options may need to be developed and evaluated in the LEC regional water supply planning process to modify the current Supply-Side Management Plan. District staff does not consider this concern to be influential to establishing minimum level technical criteria for Lake Okeechobee.

Lake Okeechobee Littoral Zone and Associated Fish and Wildlife Values

The following fish and wildlife values for Lake Okeechobee were identified in a multiagency workshop held in March, 1997 (Havens and Rosen, 1997):

- A commercial and recreational fishery valued at over $480 million dollars (Furse and Fox, 1994)

- A rich avifauna community that includes wading birds, migratory waterfowl, and federally-designated endangered snail kite and wood stork (Richardson and Harris, 1995; Smith et al., 1995)
- Ecotourism and recreation, including fishing, hunting, and bird and wildlife observation

These values depend on the diverse mosaic of natural vegetation that characterizes the lake's littoral zone (Richardson and Harris, 1995; Smith et al., 1995). The integrity of the littoral zone depends an maintaining a favorable hydrologic regime that avoids "drowning" plant and animal communities through maintenance of water levels that are too high, or excessive drying of the littoral zone substrate that will destroy or modify existing wetland communities.

Navigation/Recreation

When lake levels fall below 12.56 ft NGVD, navigation of the Okeechobee Waterway becomes impaired. At levels below 11 ft NGVD, access to the lake for fishermen and other recreational boaters becomes limited to maintained channels and boat trails, especially in the southern and western portions of the lake. Once water levels drop near 10 ft NGVD, recreational access to the lake becomes significantly restricted, since much of the littoral zone is exposed as dry land or contains only a few inches of water.

Other Considerations

Other factors to consider include the need to provide water supply to the Everglades Agricultural Area, the Seminole Indian Tribe, and the Caloosahatchee and St. Lucie Basins. During drought conditions, agricultural water needs within these basins are estimated on the basis of weather, soil, and crop conditions. Using Supply-Side Management (Hall, 1991), the amount of water in storage and the proportion that is available for allocation are calculated. Based on this calculation, water is allocated as a percentage of the flow volume that would be needed to meet normal dry season irrigation demands in each basin. The allocation is adjusted on a monthly or weekly basis to allow for changes in regional and local conditions. The Governing Board has the authority to adjust these allocations based on local conditions (**Table 2**). Special conditions may apply in the St. Lucie Canal Basin during periods when water levels in coastal canals are higher than the stage in Lake Okeechobee. During such periods, no additional water can be supplied from the lake, and water from the basin may in fact, flow back into the lake to enhance regional supplies. Also, in the Caloosahatchee Basin, water releases from the lake may periodically be required to improve water quality conditions in the canal, when algae blooms or saltwater contamination occur at the S-79 Structure (USACE, 1991).

Water Resource Functions and Significant Harm

Water Supply and Water Storage

During years of normal rainfall, the lake's regulation schedule allows for an ample supply of water to be stored in the lake for later use during the dry season. The amount of rainfall that falls in South Florida is highly variable and in some years can result in drought conditions. Review of historical records shows that when lake levels fall below 11 ft NGVD, these levels continue to fall rapidly causing water shortage restrictions to be imposed for the LEC and Lake Okeechobee service areas. When lake stages fall below 10.5 ft NGVD, the structural limits of the lake's outfall structures and regional water conveyance system make it increasingly difficult to discharge water from the lake to the LEC. These discharges are necessary to protect the coastal aquifer against saltwater intrusion.

To examine the water supply and water storage functions of the lake, staff reviewed the District's existing drought management plan known as the *Supply-Side Management Plan for Lake Okeechobee* (Hall, 1991), which was developed to avoid extreme drawdowns that impact South Florida's regional water supply. This plan currently serves the District as the basis for making water management decisions during periods of low rainfall. Supply-side management has been in operation since 1982 and provides (a) water allocation strategy for all users to conserve water and avoid severe drawdowns of the lake, (b) a method for holding enough water in the lake for anticipated high demand periods, and (c) a defined low water level stage that provides enough water in the lake to protect the coastal aquifer from the threat of saltwater intrusion. For a more detailed discussion of how these management zones are operated during low rainfall periods to maintain coastal ground water levels and provide water to the EAA and the Caloosahatchee River and St. Lucie Canal basins, see SFWMD (1987) and Hall (1991).

In general, under the current lake regulation schedule and normal rainfall conditions, water levels in Lake Okeechobee will not fall below 11.0 ft NGVD. Exceptions occur when there is a regional drought. Under drought conditions, the District implements the Supply-Side Management Plan designed to protect the water resource functions listed in **Table 3** and keep sufficient water in the lake to maintain levels above 11 ft NGVD by the end of the dry season. However, when drought conditions are severe and water levels are predicted to drop below 11 ft NGVD by the end of the dry season, the District Governing Board has the authority and responsibility to review water conditions and determine the amount that can and should be released from the lake to downstream users.

The District's water allocation strategy is based on six critical lake water management zones that require specific actions to be taken once water levels fall within each designated zone. These include six water shortage zones: management zones A through D, a warning zone, and a watch zone (**Figure 12**).

The top of Zone A, as shown in **Figure 12**, represents a sufficient amount of water stored in the lake to meet expected dry season demands when normal rainfall, evapotranspiration, and water use demands prevail within all basins. If water levels fall below Zone A, Phase 1 and Phase 2 water use restrictions may be imposed by the

Table 3. Key Water Resource Functions of Lake Okeechobee and Proposed Minimum Level Criteria.

Water Resource Function	Proposed Minimum Level	Comment
Protect Biscayne Aquifer Water Quality	The top of Supply-Side Management Zone C (**Figure 12**) from April 15 through July 15 represents the proposed significant harm limit to protect Lake Okeechobee's water supply.	When water levels fall below the top of Zone C, there is a significant risk that not enough water is available in the lake to maintain freshwater heads in LEC canals necessary to protect the Biscayne aquifer from migration of the freshwater/ saltwater interface. Resulting damage will take multiple years to recover.
Provide Fish and Wildlife Habitat	Measurable harm occurs to the littoral community and it's associated ecological values when lake levels remain below 11 ft NGVD.	Existing scientific information is not currently sufficient to establish a minimum duration or return frequency for the proposed minimum level. Research over the next several years will better define ecologically-based duration and return frequency criteria.
Maintain Navigation and Recreation Access	Drawdowns below 10 ft NGVD results in significant harm to navigation and recreational use of the lake.	Drawdowns below 10 ft NGVD significantly impact navigation along the Okeechobee Waterway, restricting navigation and recreational use by the public and causing significant economic loss to local businesses

District's Governing Board for the LEC, the EAA, and the Caloosahatchee and St. Lucie basins. The top of Zone A sets a minimum lake stage of 11 ft NGVD at the end of the dry season (May 31), and a minimum lake stage of 13.5 ft NGVD on October 1 in order to avoid water shortage restrictions for lake users. However, once water levels fall within Zone C, there is increased risk that not enough water is stored in the lake to protect the Biscayne aquifer from saltwater intrusion. For this reason, Phase 3 and Phase 4 water restrictions could be imposed when water levels fall below Zone C. Thus, the top of Zone C as shown in **Figure 12** represents the minimum level, or significant harm limit, for Lake Okeechobee's water supply.

Protection of Fish and Wildlife Habitat

The littoral zone of Lake Okeechobee developed in its present location after construction of the Herbert Hoover Dike in the mid 1950s and the adoption of a water regulation schedule that lowered the lake and exposed an area of lake sediments that was once overlain by deep water (Havens et al., 1996). Today this littoral zone covers 22 percent of the lake's surface area and supports a diverse mosaic of native plants and animals. To fully understand the ecological impact that each of these water level regimes have had on the lake, it is important to consider how dike construction and water management have changed the relationship between lake stage and littoral zone flooding and drying (**Figure 13**)

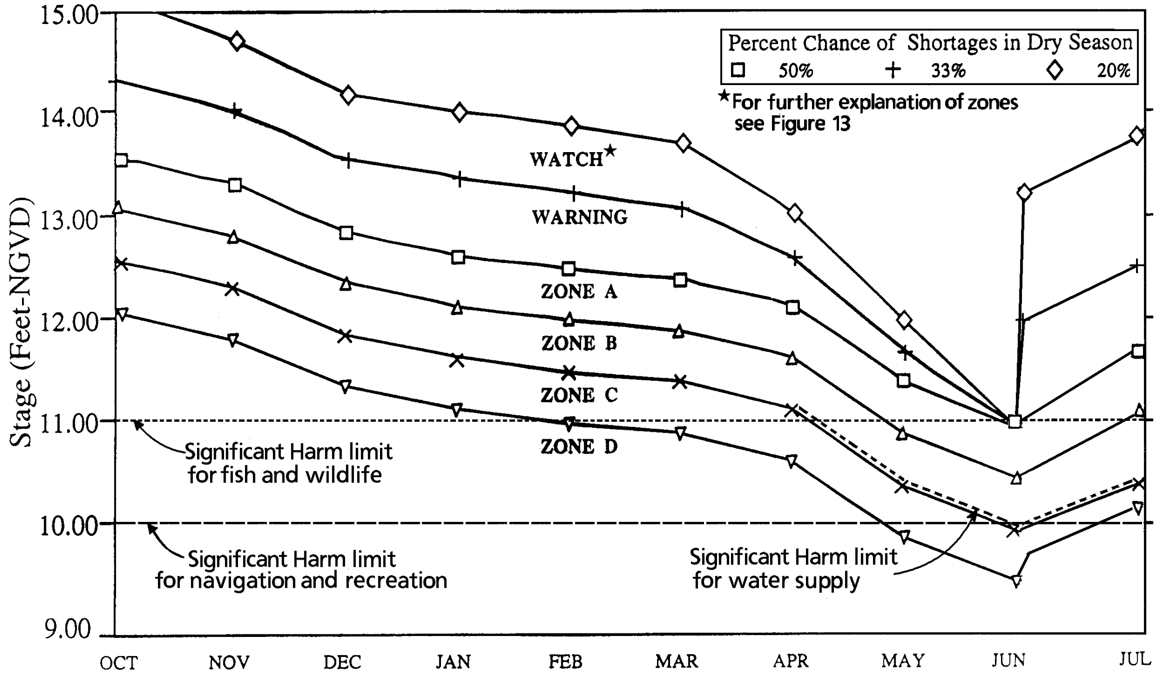

Figure 12. Lake Okeechobee Water Supply Management Zones (Hall, 1991).

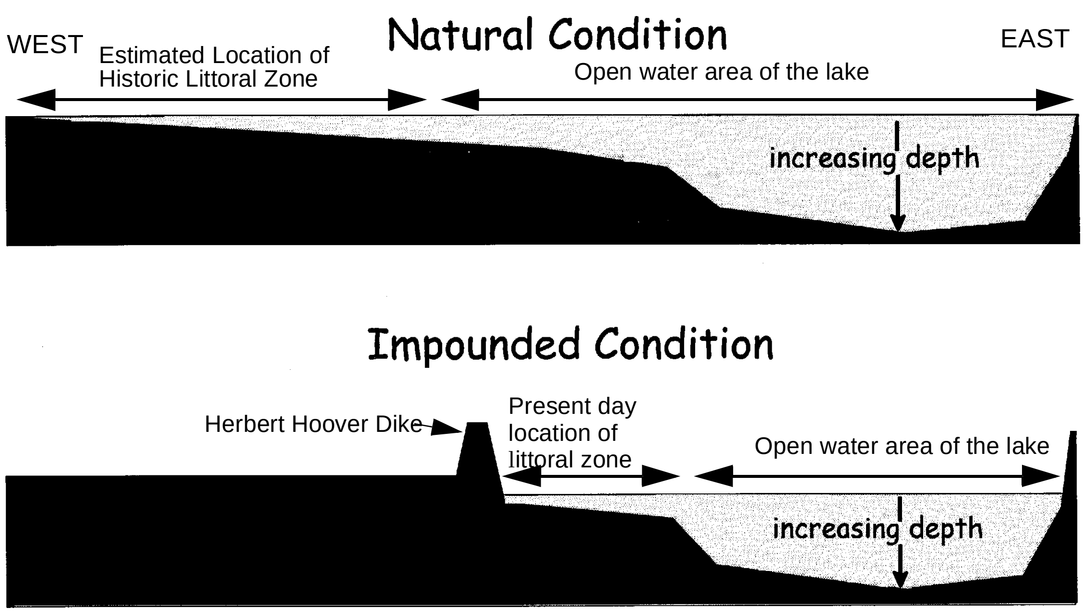

Figure 13. Cross-Section of the Littoral Zone and Open Water Areas of Lake Okeechobee under Natural Conditions versus the Current Impounded Condition (conceptual diagram - not to scale).

Predevelopment Lake Okeechobee was considerably larger in surface area, with a littoral zone that extended over a wide expanse of low-gradient land to the north, west, and south of the lake's open water region (Havens et al., 1996). To the south, the littoral zone was contiguous with the Florida Everglades. Seasonal variations in lake levels according to historic accounts (Brooks, 1974) and output of the Natural Systems Model (version 4.5) indicate the lake ranged between 16 and 22 ft NGVD under natural, predrainage conditions, and periodically flooded and dried out the larger historic littoral zone region. Today the smaller impounded littoral zone is constrained between the Herbert Hoover Dike and a relatively steep shelf at the eastern littoral edge, where it meets the open water area of the lake (**Figure 13**). As a result of construction of the dike, when lake stage reaches 15 ft NGVD, the entire littoral zone is flooded. Further increases in stage simply result in deeper flooding of the littoral region, with no opportunity for outward expansion of the lake across shallow wetland habitat. Due to the rather steep slope of the eastern littoral zone shelf, when lake stages remain at 11 ft NGVD or less, most of the littoral zone is dry, and there is little opportunity for expansion of shallow wetland habitat into the lake. The only exception is at the south end of the lake, where a more gradual depth gradient occurs. At low water levels, submerged plant growth in this region may actually benefit from increased light penetration. However, such benefits also occur when lake stages are between 12 and 13 ft NGVD.

Distribution of Littoral Zone Vegetation. The current distribution of plants in the littoral zone has been quantitatively linked to localized variations in hydroperiod (Richardson et al., 1995). Particular plant assemblages support certain kinds of fish and wildlife (Aumen and Wetzel, 1995). The two examples below illustrate this point.

In the Moonshine Bay region, deep within the western littoral marsh, there is a large expanse of spike rush (*Eleocharis*), a native sedge that provides primary foraging habitat for the endangered snail kite (Bennett and Kitchens, 1997). This pristine, nutrient poor community is characterized by two to three feet of standing water during the wet season, a hydroperiod of greater than 95 percent, interspersed emergent plants, and an associated periphyton community (Steinman et al., 1997). In many respects, the Moonshine Bay vegetation community closely resembles pristine interior areas of the Everglades (McCormick et al., 1997). The periphyton community in this region of the lake supports a large population of native apple snails, which are the primary food resource of the endangered snail kite. The spike rush community is also important spawning habitat for largemouth bass and other important sport fish.

At the interface between the littoral zone and the open water region of the lake, there exists another important community, dominated by giant bulrush (*Scirpus*). This community is critical habitat for both largemouth bass and black crappie, two of the most important sport fish in the lake (Fox et al., 1995). In a recent analysis, Furse and Fox (1994) calculated that the economic value of this habitat is $48,828 per acre, for a total value of $174 million for the entire 3,576-acre habitat.

In addition to native plants, the littoral zone now contains 15 invasive exotic species, including melaleuca (*Melaleuca quinquenervia*) and torpedo grass (*Panicum repens*). Melaleuca was introduced by the USACE to stabilize soils on the newly constructed Herbert Hoover Dike and torpedo grass was introduced into the watershed north of Lake Okeechobee as a forage crop for beef cattle. Both plants have expanded over thousands of acres in the marsh, displacing native vegetation. The District has been conducting a multimillion dollar program to eradicate melaleuca, and it remains to be seen whether native plants will recolonize treated areas.

In the case of torpedo grass, there is no proven method for control, short of applying a general-action herbicide that kills all vegetation. Research is being conducted by District and University of Florida scientists assessing the application of general action herbicides, along with controlled fires, as methods for controlling torpedo grass. Results to date are mixed; in some cases, there has been nearly total control in herbicide-treated experimental plots, while in other cases, control has been less than 20 percent. It also remains unclear whether native plant communities can consistently recolonize sites that were formerly occupied by torpedo grass.

There are two important features associated with the vast expanses of torpedo grass that now occur in the littoral zone of Lake Okeechobee. First, they are poor habitat for fish and other aquatic animals. The growth form of torpedo grass is much like a hay field with little or no open water area for aquatic organisms to move about, feed, or capture prey. Nighttime dissolved oxygen levels in torpedo grass stands have been observed to fall to zero. Such conditions are not suitable for most aquatic animals. Secondly, torpedo grass has continued to expand in the marsh over the last decade, and it now encircles Moonshine Bay, one of the deepest regions of the marsh that still is dominated by native spike rush. Within this community, there also are islands of torpedo grass on higher elevation sites (K. Havens, personal communication). Expansion outward from these isolated islands is a constant threat to the native plant community, and may occur rapidly if low lake levels frequently occur.

Results from a recent study of the lake’s vegetation communities support this view. Richardson et al. (1995) noted that hydroperiod within native spike rush communities averages 96 percent, while hydroperiod within torpedo grass and melaleuca communities averaged near 80 percent and 78 percent, respectively. Hydroperiod is defined as the percent of time water inundates a wetland on an annual basis. Richardson et al. (1995) concluded that (a) hydrologic variables appear to be the major determining factor in the vegetative patterns seen in the Lake Okeechobee marsh; and (b) higher elevation areas of the marsh that now contain melaleuca and torpedo grass may expand if hydroperiods are shortened due to lower lake levels.

Lake Okeechobee Research Findings. A principal finding from wading bird and fisheries research, conducted during the five-year Lake Okeechobee Ecosystem Study (Aumen and Wetzel, 1995) was that some variation in lake levels are necessary for maintaining a healthy littoral community. Smith et al. (1995) recommended spring lake level recessions from above 15 ft NGVD to below 13 ft NGVD, in order to concentrate prey resources (macro invertebrates and small forage fish) and promote wading bird nesting on the lake. Periodic (every several years) declines in lake level to below 12 ft NGVD also were considered beneficial, because they can invigorate willow stands, allow limited fires to burn away cattail wrack, recycle nutrients, and encourage establishment of successional vegetation complexes. These moderate or periodic water level recessions will not cause significant harm to the community, unless they occur for long durations. In fact, the hydrologic restoration goal for the lake in the Comprehensive Everglades Restoration

Plan (USACE, 1999) is for fluctuations of lake levels between 12 and 15 ft NGVD, in as many years as possible (Havens, Manners, and Pace, 1998).

Results of recent observational and experimental research conducted by staff at the District and wetland ecologists at the US Army Corps of Engineers Waterways Experiment Station (USACE-WES) indicate that low water levels (<25 cm above the sediment surface) allow for rapid invasion of torpedograss. In the critical Moonshine Bay region of the Lake Okeechobee littoral zone, these low water levels occur when lake stage falls to 11 ft NGVD.

Relationship between Lake Stage and Impacts to Fish and Wildlife. Quantitative relationships between lake levels and significant harm impacts were evaluated in this study based on (a) output from a GIS model that relates flooding and drying of the littoral zone to lake stage, (b) information regarding fish and wildlife usage of different regions of the littoral zone and open water areas of the lake, (c) direct observations of changes in the littoral community during and after major drought events and (d) results of experimental research that relates exotic plant growth rates to water levels.

When lake levels drop to 11 ft NGVD, GIS models indicate that 94 percent of the littoral marsh is dry and no longer functions as aquatic habitat for fish and other aquatic-dependent wildlife, because water levels are at, or below ground surface (**Figure 14**). Certainly there is a loss of wetland habitat as lake levels decline over a wider range of depths, starting at 15 ft NGVD, when the entire marsh is submerged. However, it is when lake levels fall from 12 to 11 ft NGVD that critical spike rush and giant bulrush habitats become dry, and can no longer provide habitat for fish and other aquatic animals. When lake levels drop to 11 ft NGVD, the bulrush community also experiences competition with the nuisance plant cattail (C. Hanlon, personal communication), further affecting habitat quality for fish and other aquatic dependent species of wildlife.

Lake Okeechobee, the WCAs, and Everglades National Park represent important habitat for the federally-designated endangered snail kite. These areas are hydrologically interconnected by the C&SF Project and their water levels are strongly correlated (Bennetts and Kitchens, 1997). During a regional drought, loss of food resources (apple snails) due to drying of multiple habitats could represent a serious threat to the survival of the snail kite. Under these conditions the littoral zone of Lake Okeechobee, especially Moonshine Bay, may function as a habitat of last resort if water levels can be maintained above 11 ft NGVD.

When lake levels drop to 11 ft NGVD, the spike rush habitat of Moonshine Bay is exposed and becomes more susceptible to invasion by torpedo grass. Controlled experiments conducted at the University of Florida have shown that torpedo grass growth rates are significantly reduced by 30 cm. (1 foot) of standing water (Thayer and Haller, 1990). Growth is rapid when standing water occurs at the soil surface. In contrast, the native plant spike rush is a marsh species that thrives in Moonshine Bay with water depths up to 3 foot NGVD deep (K. Havens, communication).

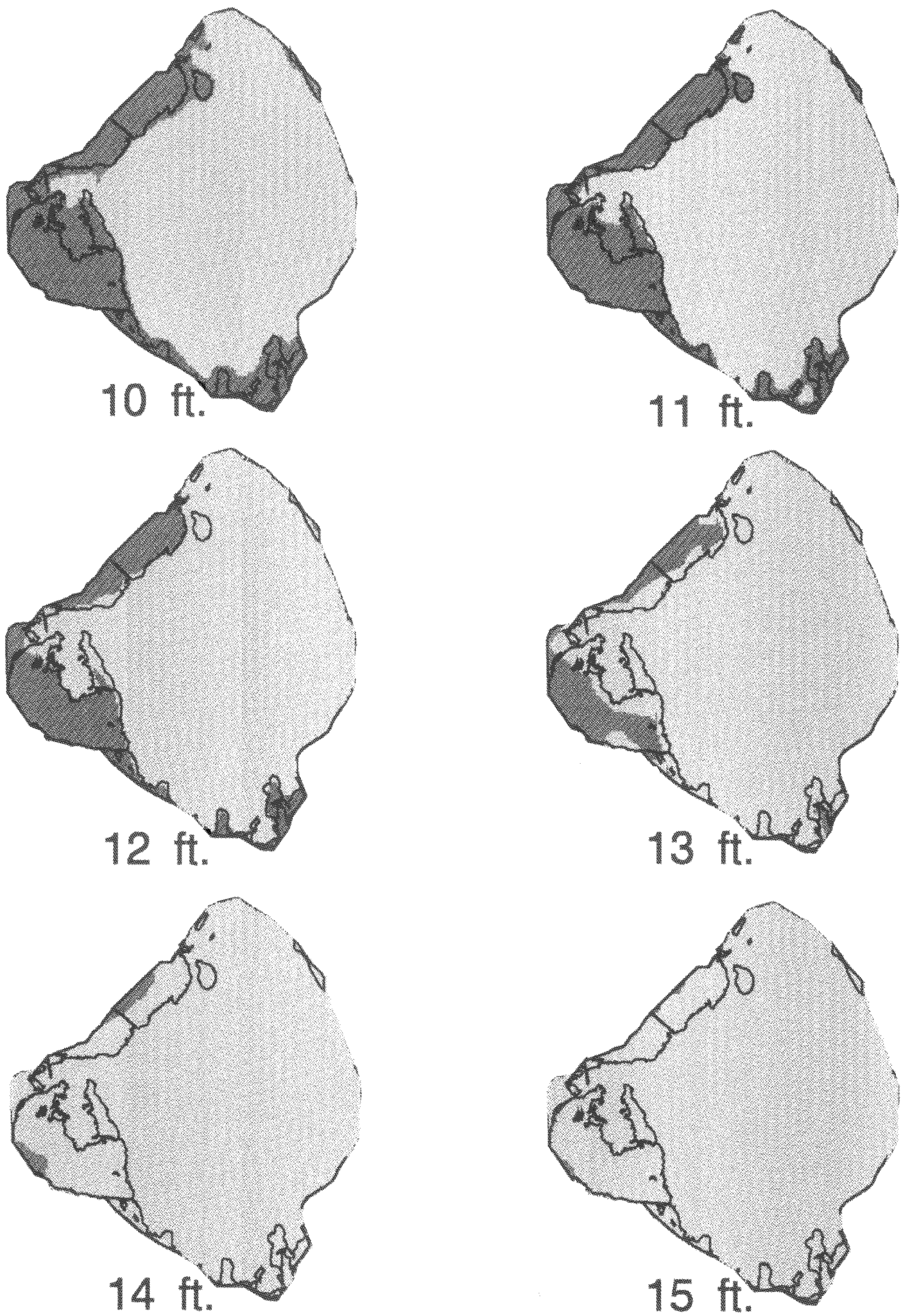

Figure 14. Exposed Land (indicated by dark gray areas) in Marsh Zones and Percentage of Total Marsh Zone Exposed for Six Water Level Conditions in Lake Okeechobee. At water levels below 10 ft NGVD and above 15 ft NGVD, there is 100 percent and 0 percent exposure, respectively.

Recent research conducted by the USACE-WES wetland ecology group supports the view that maintaining lake levels above 11 ft NGVD helps prevent the expansion of torpedograss within the littoral zone. That research also helped defined a water depth below which the risk of expansion is high. For the Moonshine Bay region of the lake's littoral zone that depth corresponds to a lake stage of 11 ft NGVD.

Changes in plant community structure in a nearby region of the marsh between 1997 and 1998 provide some evidence of how the Moonshine Bay community might be affected by several months of drying. In summer of 1997, low lake levels resulted in the drying of a large region of the southwestern corner of the littoral zone dominated by spike rush. This area was dry for approximately two months, during which time the soils became desiccated and devoid of living plants. Reflooding occurred in the fall of 1997. In summer 1998, District biologists noticed this region had developed a mixture of spikerush and torpedo grass. In contrast, torpedo grass did not appear to expand substantially in Moonshine Bay, which remained flooded with approximately one foot of water during the summer of 1997 (K. Havens and C. Hanlon, personal communications).

When lake levels drop to 11 ft NGVD, large areas of the marsh become available for colonization by melaleuca. After the 1989/90 drought, District scientists and aquatic plant managers observed a large increase in the density and areal extent of new melaleuca seedlings in the marsh, despite extensive management efforts to eradicate this exotic plant. Maintenance of standing water over the marsh may play an important role in limiting the expansion of this exotic plant within the littoral zone. This reflects the fact that melaleuca seedlings display little or no germination while submerged (Lockhart, 1995; C. Hanlon and D. Thayer, personal communications). Once the plants germinate, however, they are able to continue growth even if the soil is reflooded.

Based on the information presented above, Lake Okeechobee's littoral zone and associated fish and wildlife habitats are impacted when lake levels drop to 11 ft NGVD. Existing ecological information concerning the lake and its response to low water levels are not currently sufficient to establish a minimum duration and return frequency for the lake. A number of research projects have been proposed over the next several years to determine the response of littoral zone vegetation to various lake levels and hydroperiods. This research should provide the District with better information to define a biologically-based duration criterion. However a science-based criterion for return frequency will likely remain elusive, given the long-term (decades) nature of data that would be required to support that attribute.

Relationship between Lake Stage and Navigation and Recreation Access. The Okeechobee Waterway crosses South Florida from the Atlantic coast to the Gulf of Mexico via the St. Lucie Canal, Lake Okeechobee, and the Caloosahatchee River. The authorized project channel depth across Lake Okeechobee from Moorehaven to Port Mayaca is 8 feet deep when the water level in the lake is at 12.56 ft NGVD. Another channel, which follows the south rim canal from Clewiston to the St. Lucie canal, is 6 feet in depth when water levels are at 12.56 ft NGVD. When water levels fall to 11 ft NGVD, boat traffic along the Lake Okeechobee waterway is restricted to boats with drafts of four feet or less. This limits most sailboats more than 30 feet in length and most powerboats of more than 40 feet in length. At a lake elevation of 10 ft NGVD, the Lake Okeechobee Waterway is impassible to most fixed keeled sailboats. Recreational access within the lake is also limited, with virtually no access to the littoral areas.

Proposed MFL Criteria for Lake Okeechobee

Criteria Development

In an effort to address the often competing water resource functions of the lake (listed below) the following dual minimum water level criteria were developed for Lake Okeechobee. These criteria were developed based on a review of available scientific data summarized in this report, including the following:

- Review of the District's Supply-Side Management Plan for Lake Okeechobee (Hall, 1991)
- Ecological results of a five-year study of the lake (Aumen, 1995) and its response to changing water levels
- Results from a GIS model of the lake that was used to estimate the percent of the littoral zone that is dry or flooded at various lake stages
- Hydroperiod requirements of native wetland vegetation based on historic records of plant community structure and water level fluctuations in the lake
- Controlled experiments conducted by the USACE-WES that indicate rapid torpedograss expansion can be expected if the littoral zone becomes dry
- Navigation and boat access requirements

The following dual MFL criteria for Lake Okeechobee focus on achieving a balance among, and preventing significant harm to, four key water resources functions of the lake (not listed in priority order):

- Protect ecosystems that provide fish and wildlife habitat within the littoral zone,
- Provide water supply and storage for the LEC Planning Area,
- Protect the Biscayne aquifer against saltwater intrusion
- Providing navigation and recreational access to the lake during dry periods

Table 3 provides a comparison of proposed minimum levels presented in this report for each of the above key water resource functions. Review of this information shows that significant harm, defined for each water resource function, occurs within the range from 11 to 10 ft NGVD. The top of Supply-Side Management Zone C as shown in **Figure 12**, from April 15 through July 15, represents the significant harm limit for protecting water supply during dry periods. The rationale for utilizing Supply-Side

Management is that when water levels fall below the top of Zone C, there is serious risk that not enough water can be stored in the lake to maintain a freshwater head within coastal canals to protect the Biscayne aquifer from the threat of saltwater intrusion (i.e., significant harm). In contrast, significant harm occurs to fish and wildlife habitat (i.e., the littoral zone) when lake stages recede below 11 ft NGVD anytime of the year. Finally, drawdowns of the lake below 10 ft NGVD result in significant restrictions to navigation and recreational use of the lake.

District staff reviewed the minimum water level criteria proposed for each of the four water resource functions presented above and integrated them into dual minimum water level criteria for Lake Okeechobee to manage water levels during periods of low rainfall. The dual criteria consist of an operational component and a longer term water supply planning component as presented below.

Description of Criteria

Minimum water level criteria proposed for Lake Okeechobee consist of two components: operational and water supply planning criteria. Operational criteria are used to identify when the MFL has been exceeded on a day-to-day basis. Water Supply Planning Criteria provides water managers with information as to how often, and for what duration, the MFL may be exceeded based on the expected frequency of natural drought events. These criteria are defined as follows:

- Operational MFL Criteria - During most years, water levels in Lake Okeechobee should not fall below 11 ft NGVD. However, in order to make water deliveries from the lake to the LEC Planning Area, the water level in the lake may occasionally fall below 11 ft NGVD from April 15 to July 15 as long as it does not drop below the top of Supply-Side Management Zone C, as shown in **Figure 15**.
- Water Supply Planning MFL Criteria - The water level in the lake should not fall below 11 ft NGVD for more than 80 days duration, more often than once every six years, on average (This criterion was developed based on historical data because sufficient ecological data are not available--see discussions of *Minimum Duration and Return*

Frequency in the Lake Okeechobee Section of **Chapter 2** and *Operational* and *Water Supply Planning* MFL criteria below).

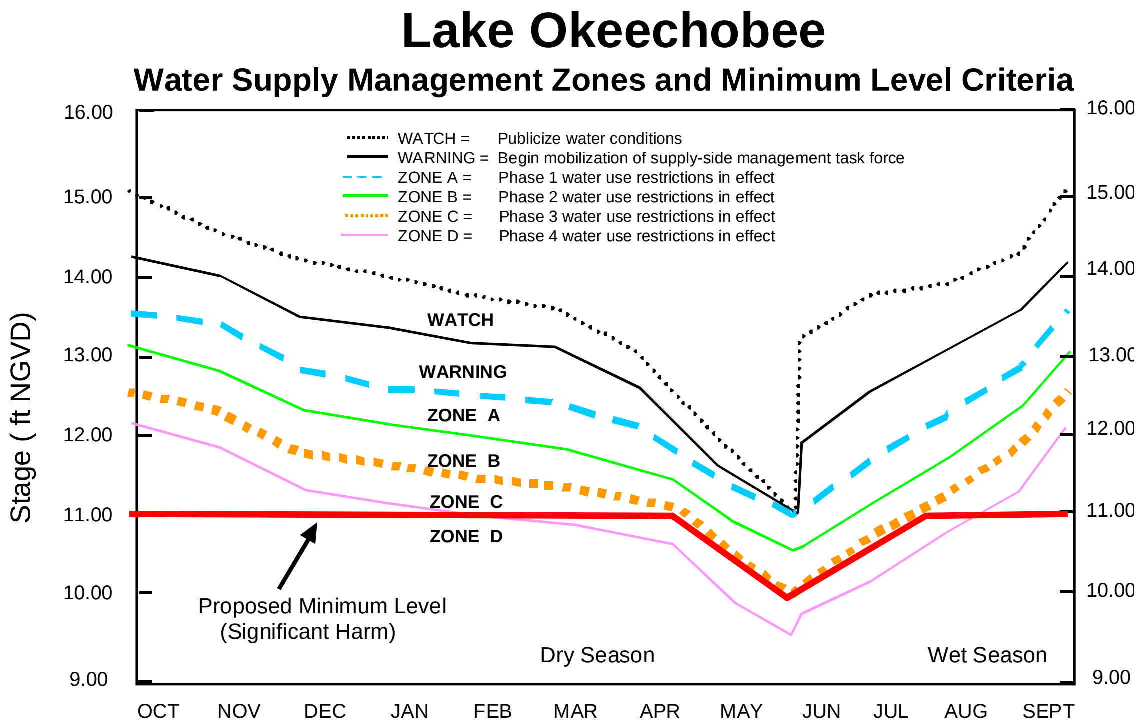

Figure 15. Proposed Minimum Level for Lake Okeechobee in Relation to Supply-Side Management Zones A through D.

Operational MFL Criteria

From an operational standpoint, the proposed minimum level for Lake Okeechobee is 11 ft NGVD, except for the period of April 15 to July 15. During this 90-day period, the proposed minimum level for the lake is the top of Supply-Side Management Zone C, which is 11 ft NGVD on April 15, and may reach a minimum of 10 ft NGVD on May 31, and returns to 11 ft. on July 15 **(Figure 15**). The 11 ft. criterion was selected, in part, based on the need to provide a backup supply of water within the lake to protect the Biscayne aquifer from the threat of salt-water intrusion. This backup supply of water represents approximately one foot of water off the lake, between lake stages of 11 and 10 ft NGVD, or 327,000 ac-ft. of water as shown in **Figure 12**. During actual drought periods, the Governing Board has the flexibility to deliver Lake Okeechobee water as necessary to optimize protection of South Florida's water resources.

Review of historical data (see below) shows that water levels in Lake Okeechobee have generally remained above 11 ft NGVD (with two exceptions) from mid-July through the first two weeks of April. It should also be understood that, under current water shortage management practices, that if water levels begin to decline during drought conditions and fall below the top of Zone C or into Zone D, Phase 3 and Phase 4 water restrictions would be contemplated for users well before the minimum water level is reached. These restrictions are designed to keep the lake from reaching the designated level that may cause significant harm to the region's water supply or the ecological resources of the lake.

Water Supply Planning MFL Criteria

The above operational criteria were developed to help water managers identify when the minimum lake level has been exceeded on a day-to-day basis. However, in the development of these criteria it was also recognized that if the lake fell below 11 ft NGVD every year, or once every several years, this would clearly have a major impact on both the ecology of the lake and its ability to function as a regional water storage facility. Therefore, for water supply planning purposes, the MFL must also include some kind of acceptable duration and return frequency criteria that account for regional drought cycles during which the lake may recede below 11 ft NGVD due to natural conditions.

Duration is defined as the number of consecutive days that water levels remain below 11 ft NGVD without causing significant harm to the water resource functions of the lake. Return frequency is defined as the acceptable number of years between these low water events (water levels falling below 11 ft NGVD). This information is needed by the District in its water supply planning process to account for the effects of natural drought cycles on lake water levels versus those caused by water supply withdrawals. These criteria will be incorporated into the District's ongoing water supply planning computer simulations to predict how well or poorly a specific water supply alternative performs over the long-term. Ideally, the duration and return frequency criteria should be based on scientific information obtained from ecological research on the lake.

Unfortunately, our current understanding of the ecosystem in not at a level that permits establishment of science-based criteria for these attributes. Until better scientific information is available, the District proposes to use the 1952-1995 historical period of record (period of time following construction of the Herbert Hoover Dike) to calculate an interim duration and return frequency component for the Lake Okeechobee MFL. The historical record (**Table 4** and **Figure 16**) shows that water levels fell below 11 ft NGVD a total of seven times over the 43-year period of record (once every 6.1 years) in response to low rainfall periods with an average duration of 82 days. Based on these data, the interim water supply planning criteria for Lake Okeechobee is water levels should not fall below 11.0 ft NGVD more often than once every 6 years (on average) with a duration no greater than 80 consecutive days.

EVERGLADES

Resource Functions

Minimum water level limits need to be established within the Everglades (the WCAs, Holey Land and Rotenberger WMAs, and Everglades National Park) to prevent the occurrence of extreme low water events that impact the sustainability of the

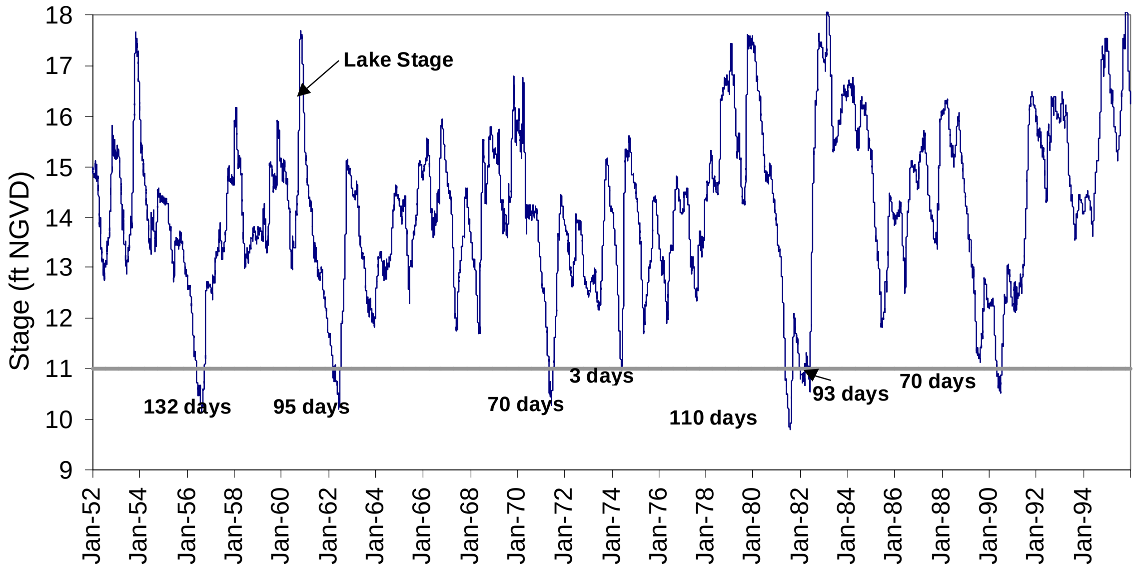

Figure 16. Hydrograph Showing Historical Lake Stage (1952-1995) and the Number of Times and Duration that Lake Stages Fell Below 11 ft NGVD

Table 4. Occurrences of Water Levels Below 11.0 ft NGVD, Based on the 1952-1995 Historical Period of Record

No. Times Water Levels Below 11 ft NGVD	Return Frequency (years)	Average Duration Below 11 ft NGVD	Dates Criteria Were Exceeded
7	once every 6.1 years	82 days	1) May 26 - Oct. 5, 1956 (132 days) 2) April 4 - June 29, 1962 (95 days) 3) April 30 - July 8, 1971 (70 days) 4) May 31 - June 2, 1974 (3 days) 5) May 13 - Aug. 30, 1981 (110 days) 6) Jan. 2 - May 26, 1982 (93 days) 7) May 4 - July 12, 1990 (70 days)

ecosystem. The following six water resource functions were considered in the development of minimum water level criteria for the Everglades:

- Provide ground water recharge to prevent saltwater intrusion of the Biscayne aquifer, South Florida's primary drinking water source
- Provide hydropatterns that will support Everglades food chains, substrates and habitats necessary to support wildlife, including threatened and endangered species
- Provide natural biological filtering and nutrient cycling -- trapping suspended solids and metals in sediments, detritus and living tissue,

and converting dissolved nutrients derived from rainfall, decomposition and soil oxidation into biomass.

- Provide aquatic refugia for Everglades fish, amphibians, aquatic invertebrates, and other wildlife during droughts
- Provide an Everglades ecosystem that is not degraded due to invasion by terrestrial woody vegetation and introduced exotics such as melaleuca
- Provide water flows that maintain salinity regimes and ensure survival of plant and animal communities in coastal estuaries

As noted previously, overall restoration goals for the Everglades are presently being established by the Comprehensive Everglades Restoration Plan, because this is an ongoing process. There is a potential for conflict in some areas between water levels that are established to achieve restoration and the water levels proposed in this document that are designed to prevent significant harm. As restoration goals for particular areas change or are modified over time, proposed MFLs may also be adjusted to ensure consistency.

Technical Relationships Considered in Defining Significant Harm

Importance of Hydric Soils

Protection of hydric soils (organic peat and marl) was selected as a criterion for Everglades ecosystems because of the following:

- More than 90 percent of the soils of the Everglades are comprised of either peat or marl.
- Almost all of the plants and animals that inhabit the Everglades region depend, at least in part, on the hydrologic regime that produces hydric soils. Therefore, maintenance of a hydrologic regime which protects hydric soils will also help protect other water resource functions of the Everglades such as providing fish and wildlife habitat.
- Establishment of minimum water levels will help protect the resource from overdrainage which results in soil oxidation, and fires which consume peat, lower ground elevations, impact wetlands, tree islands and wildlife communities.
- Preservation of hydric soils helps to maintain the freshwater head in the Everglades and therefore is important for maintaining ground water flows to the east (to help prevent saltwater intrusion of the coastal aquifer) and to the south to help maintain ground water base flows to South Florida's estuaries.

Based on technical information provided in this document, District staff have concluded that excessive drying of hydric soils (marl and organic peat), which leads to soil oxidation and subsidence, impacts Everglades plant and animal communities and constitutes harm to the resource that could require many years (decades or perhaps centuries) to recover. Water level reductions below those that would normally occur, may allow organic peat soils to dry out, oxidize, and burn more often, or more severely than would occur during normal dry season conditions. Continual destruction of soils disrupts or destroys the overlying plant communities that provide food, shelter, and habitats for Everglades fish and wildlife. Continual loss of these soils threatens both the integrity and sustainability of the Everglades ecosystem. Although the exact conditions that make it possible for peat soils to oxidize at a significant rate or burn excessively are not completely known throughout the region, the proposed criteria are based on best available data from a number of different sources. The attempt has been made to define conditions where increased soil losses are more likely to occur. Whereas one or more inches of peat may oxidize during a very dry year and many inches or feet of peat may be lost during a severe fire, even under ideal condition, peat soils accrete at a very slow rate of about 0.04 to 0.06 inches per year.

Relationship Between Protected Functions and Everglades Soils

In its original condition, the Florida Everglades represented the largest single body of organic soils in the world, covering over 3,100 square miles (Stephens, 1984). Formed under anaerobic, waterlogged conditions, these soils began to subside as wetlands were drained and developed. Subsidence is caused primarily by drainage, biochemical oxidation, compaction, and burning of organic soils. Agricultural development south of Lake Okeechobee has substantially reduced ground water levels within the EAA. Some areas have recorded peat losses of up to 5 to 6 feet (Stephens, 1984). Significant lowering of ground level elevations has also occurred in the Everglades, primarily along major drainage canals (**Figure 17**). In the natural system, Everglades peat functioned as a regional freshwater sponge, absorbing rainfall and creating a hydrostatic head higher than what is currently maintained in the system today (Stephens, 1984). Prior to development, ground water flows to the coast occurred from recharge areas located behind the coastal ridge (Parker et al., 1955). Once areas behind the ridge were drained for development, regional ground water flows to the east coast became governed by ground water heads maintained in the Everglades. These flows move primarily eastward from the Everglades to the LEC Planning Area via ground water or the regional canal network and help stabilize the freshwater-saltwater interface (Fish and Stewart, 1991). The continued loss of peat resources in the Everglades, and associated loss of freshwater head, has the potential to further reduce ground water flows to the east and thus increase the threat of saltwater intrusion during drought periods. Saltwater intrusion into coastal wellfields has been the chief threat to South Florida's water supply since drainage activities began in the early 1900s (Stephens, 1984). Providing adequate minimum water levels in the Everglades during low rainfall years is important to preserve peat resources and future water supplies.

Everglades Water Levels and Soil-Plant Community Relationships

Peat Formation and Soil Loss in the Everglades

Peat is formed in the Everglades from remains of either slough vegetation (Loxahatchee peat), or sawgrass (Everglades peat) communities. Deep water (up to two

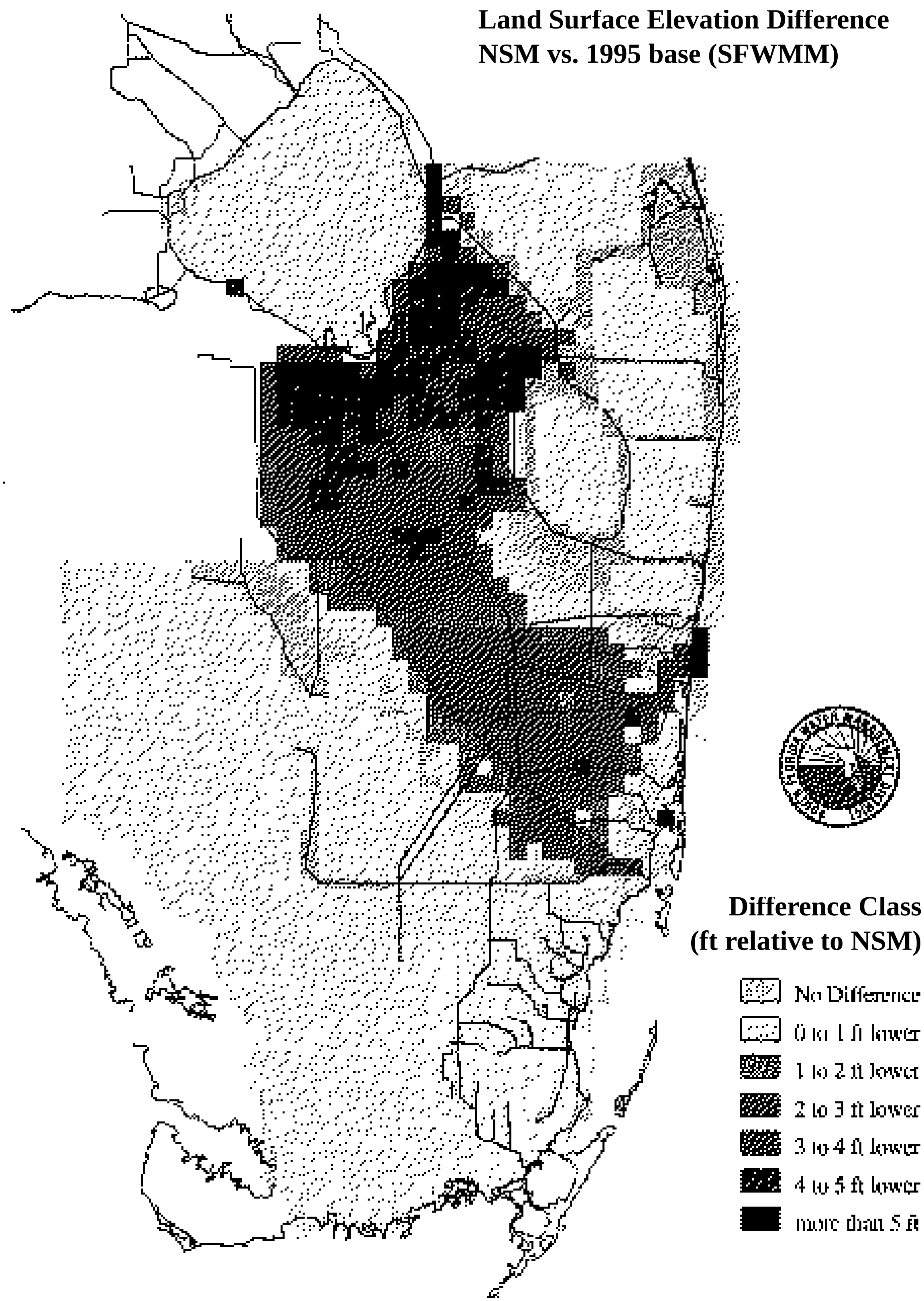

Figure 17. Soil Subsidence in the Everglades Region of South Florida.

feet deep) and long hydroperiod conditions tend to favor the formation of Loxahatchee peat, while shallower water depths and shorter hydroperiods favor the production of Everglades peat (Gleason and Stone, 1994; Tropical BioIndustries Inc., 1990). Based on soil surveys conducted by Jones (1948), Loxahatchee peat was found primarily in WCA-1, the northern portion of WCA-2A, western WCA-3A, WCA-3B, and the Shark River Slough region of Everglades National Park. Everglades peat was found primarily in southwestern WCA-2A, northeastern WCA-3A, northern WCA-3A and in the Holey Land and Rotenberger WMAs. **Figure 18** (adapted from Jones, 1948) shows the distribution of the major hydric soil types (Loxahatchee peat, Everglades peat, Perrine marl, Ochopee marl, and Rockland marl) found in the Everglades during the mid-1900s. The map of hydric peats is superimposed on a present day map of the hydrologic infrastructure, to show the relationship of the location of present day canals to associated water management gauges.

Formation of peat soils requires near permanently flooded or saturated soils with water depths averaging 1.5 to 2.0 feet deep and a hydroperiod of at least 9 to 10 months duration. Dry season water table recessions should not exceed more than one foot below ground for more than 30 days during a dry year. Under these conditions, surface peats remain saturated due to capillary action, pulling moisture from the underlying ground water table to provide aquatic plants and burrowing organisms with enough soil moisture to survive dry periods. Although water levels may occasionally drop more than one foot or more below ground during a major dry period, slough aquatic plants quickly recover from buried tubers, seeds, and other resting plant structures (Tropical BioIndustries Inc., 1990).

Peat accretion is a fundamental process that is needed to maintain a functioning wetland system. Average peat accretion rates in the Everglades range from 0.04 to 0.06 inches/year (Davis, 1946; McDowell et al., 1969) to 0.11 to 0.13 inches/year for WCA-3A and WCA-2A, respectively (Richardson and Craft, 1990). There is a large body of evidence indicating that construction and operation of the C&SF Project has altered the hydrologic regime of historic soil-plant communities. In many areas of the Everglades, reduced water levels and shortened hydroperiods have reversed the process of peat accretion, resulting in the oxidation of organic soils and lowering of ground level elevations. This process is called soil subsidence. Numerous studies have reported the results of extreme droughts within the Everglades system and their effects on organic soils, plant communities, and wildlife (Loveless, 1959; Craighead, 1971; Schortemeyer, 1980; Wade et al., 1980; Zaffke, 1983; Alexander and Crook, 1984; Hoffman et al., 1994; Gunderson and Snyder, 1994). For example, during the 1981 drought, water levels in northern WCA-3A receded 2-3 feet below ground for five months. During this and similar droughts, wildfires burned the roots out from under tree islands and exposed bedrock, resulting in peat losses of more than one foot over large areas of WCA-3A (Loveless, 1959; Schortemeyer, 1980; Zaffke, 1983).

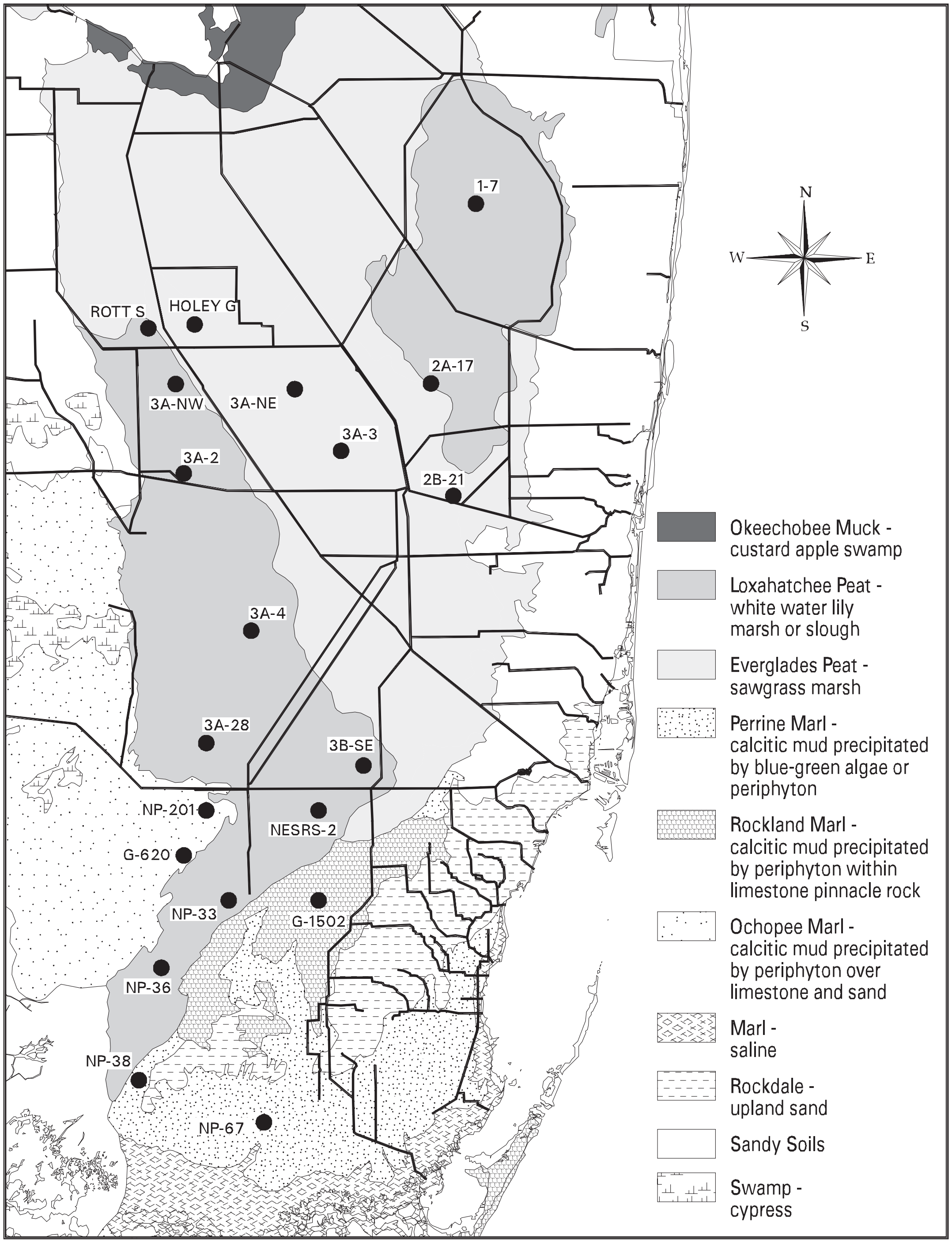

Figure 18. Spatial Distribution of the Major Hydric Soil Types within the Everglades in Relationship to the Key Water Management Gauges.

Results of a computer analysis are shown in **Figure 17**, indicating the differences in ground level elevations between predrainage conditions that were simulated by the Natural Systems Model (NSM), and present day conditions, as simulated by the South Florida Water Management Model (SFWMM). The greatest amount of soil subsidence, more than five feet in some areas, has occurred in the highly managed EAA, located south of Lake Okeechobee. Major losses within the WCAs occur primarily near the subsidence valleys that are located along major canals, the northern portion of WCA-3A, the southwest portion of WCA-2A, and northern WCA-3B (**Figure 17**). These data correlate well with recorded peat losses within the EAA (Stephens, 1984) and northern WCA-3A (Schortemeyer, 1980; Zaffke, 1983), where soil oxidation and muck fires have impacted wetland vegetation and wildlife communities. The largest peat losses occurred on tree islands, resulting in the permanent destruction of wildlife habitat. Hoffman et al. (1994) also reported the effect of fires and extensive peat losses in WCA-3A resulting from major drought events. Loss of these soils and their associated parent plant communities as a result of low water levels and reduced hydroperiods are a concern for several reasons:

- Under typical conditions, it takes from 200 to 300 years to produce one foot of peat soil. Best available data indicate that in many areas of the Everglades, peat soils are being lost from the system faster than they accumulate. The system is therefore not sustainable under the current hydrologic regime.
- Increased frequency of severe fires, which consume peat and damage Everglades plant communities and associated wildlife habitat, can result in ecological impacts that last from 3 to 10 decades (DeAngelis, 1994). These long-term changes represent significant harm to the Everglades ecosystem.
- Continued subsidence of organic soils and the associated loss of freshwater head will, over time, reduce the overall amount of water available in the regional system to protect coastal aquifer resources against saltwater intrusion, and maintain downstream estuarine communities within Florida Bay.

Marl Deposition

Marl soils or calcitic muds are formed by the precipitation of calcite by blue-green algae in submerged algal mats (periphyton) under shallow water conditions. Marl soils form primarily in areas that receive runoff that contains high calcium carbonate concentrations derived from the weathering of underlying limestone formations. Marl formation in the Everglades requires water depths averaging approximately 8 to 9 inches and a hydroperiod lasting from 7 to 10 months (Tropical BioIndustries Inc., 1990). Dry season water table recessions should not fall more than 1.5 feet below ground during a dry year (T. Armentano, Everglades National Park, personal communication). These minimum values are derived from the fact that average soil depths within the Rocky Glades, northern Taylor Slough and several other marl forming regions of Everglades National Park range between 1.0 and 1.6 feet deep. Although marl has fine texture and is highly efficient in wicking ground water to the surface, this capillary action is lost once the water table recedes into the underlying limestone substrate. Under these conditions, marl soils quickly dry out and represent one of Florida's driest environments with a water content as low as three percent, well below the tolerances of most wetland plants (Davis, 1943b). Therefore, the minimum depth that water may recede during the dry season and still allow surface marl soils to maintain capillary connections to the underlying ground water table is approximately 1.5 feet below ground.

Another important feature of marl-forming wetlands in the Rocky Glades area of Everglades National Park is the presence of thousands of solution holes formed by erosion of the karst landscape. These shallow potholes serve as important dry-season aquatic refugia for crayfish, fishes, amphibians, reptiles, and aquatic invertebrates during drought periods (Loftus et al., 1992). The majority of these solution holes range between 0.5 and 1.5 feet in depth. Prior to drainage of the eastern portion of Everglades National Park by canals, these solution holes were filled with water and aquatic organisms at the onset of the dry season (October through November) and provided food for wading birds and other wetland predators (Loftus et al., 1992). Under current conditions, the majority of these solution holes no longer retain water during the dry season and dry out completely during droughts. When water depths recede 2.0 feet or more below ground, aquatic food, consisting of fishes, amphibians, and invertebrates, are no longer available to upper trophic level consumers. Lack of aquatic refugia also means that the wetlands take longer to recolonize when water levels are restored (Loftus et al., 1992). Loss of this early nesting season feeding habitat and the disruption of the timing of prey abundance within Everglades National Park has been strongly implicated in the decline of wading bird nesting success in the southern Everglades (Beard, 1938; Loftus et al., 1992). Loss of marl soil habitats to drainage and development along the eastern edge of Everglades National Park has reduced the areal extent and quality of these early nesting season feeding sites. For these reasons, a dry season recession of no more than 1.5 feet below ground, for no more than 90 days was selected as the minimum water depth and maximum allowable duration that would protect marl soils and their associated vegetation and aquatic fauna from adverse impacts due to drainage.

Effects of Low Water Levels on Plant Communities and Wildlife Habitat

In addition to loss of peat soils, long-term reductions in water levels and shortened hydroperiods within the remaining Everglades have been found to reduce aquatic primary productivity, alter Everglades wildlife habitat by allowing terrestrial woody vegetation or introduced exotics to replace herbaceous wetland communities, and change the abundance and distribution of Everglades wildlife. In terms of areal extent, lowering of the water table and excessive drainage of the Everglades have probably impacted much larger areas of wetland habitat than the areas currently affected by nutrient enrichment.

Reduction in Primary Productivity

When wetland hydroperiods are reduced, the species composition of a major component of the Everglades food web (periphyton algae) is changed and aquatic productivity per unit area is reduced (Browder, 1981). Shortened hydroperiods and reduced productivity decrease the ability of these wetlands to maintain adequate populations of forage fish and invertebrates that support higher trophic level organisms such as wading birds. Loss of suitable feeding habitat during low rainfall years, and the carry-over effect of increased drought frequency on the overall system, are considered to be major factors that have been responsible for the decline of Everglades wading bird populations (Robertson and Kushlan, 1984; Ogden et al., 1987).

Changes in Distribution and Abundance of Wetland Plant Communities

In addition to reduced productivity, over drained areas of the Everglades commonly experience shifts in plant composition as wet-adapted organisms are replaced by species that are more tolerant of drier conditions including introduced exotics (Gunderson and Loftus, 1993). Vegetation studies summarized by Davis et al. (1994) over the past 20 years have shown a 13 percent loss in the coverage of wet prairie/slough communities and a similar gain (11 percent) in sawgrass over the same time period. These changes appear to be closely linked to the effects of lowered water levels, altered hydroperiods, and interrupted flows caused by drainage activities associated with construction and operation of the C&SF Project (Davis et al., 1994).

Changes in Wildlife Abundance and Distribution

Loftus et al. (1992) provided evidence that lowering of ground water levels and repeated drying of the Rocky Glades east of Shark River Slough and Taylor Slough have reduced the ability of these wetlands to serve as dry season aquatic refugia for Everglades fish and alligators. Severe drying of the southern Everglades may have also reduced the biomass of Everglades forage fish per unit area as compared to the predrainage system (Loftus and Ekland, 1994).

Fire

Fire is a natural force that has shaped the Everglades ecosystem. Periodic fires prevent the natural succession of fire adapted species such as sawgrass or maidencane to woody or brush vegetation. Communities maintained by fire are called fire subclimax communities. Conversely, severe fires that consume peat and damage wetland plant communities can result in ecological impacts that last from 3 to 10 decades (DeAngelis, 1994). Therefore, a potential increase in the frequency of severe fires within the Everglades relative to historic conditions is of concern.

Ecologists have examined the effects of extreme drought and fire on Everglades soils and the implications to vegetation and wildlife (Loveless, 1959; Craighead, 1971; Schortemeyer, 1980; Wade et al., 1980; Zaffke, 1983; Alexander and Crook, 1984; Gunderson and Snyder, 1994). Soil losses due to fire are relatively minor when water levels are above or near ground level. Cornwell and Hutchinson (1974) reported that Everglades fires which occur during normal hydroperiod cycles, when water levels do not recede below ground more than 4 to 5 inches, appear to have little effect on the dominant plant community. When water depths recede 1.5 to greater than 2.0 feet below ground, the peat becomes dry enough to burn (Stephens and Johnson, 1951). Under these conditions, peat fires consume the organic substrate as well as the roots of normally fire resistant plants resulting in a lowering of the soil surface and conversion to a different vegetation community, such as from aquatic slough to sawgrass (Alexander and Crook, 1973; Gunderson and Snyder, 1994). Vegetation and wildlife studies conducted in WCA-3A have shown peat fires to cause soil losses of up to one foot, with tree island communities burned down to bedrock, and subsequent loss of wildlife (Schortemeyer, 1980; Zaffke, 1983).

Incidence of severe fires in the Everglades in recent history has been qualitatively summarized and, where data were available, linked to drought periods (Robertson, 1953; Wade et al., 1980). Spatial and temporal fire patterns have been analyzed (Taylor, 1981) and ranked according to cycle dominance (Gunderson and Snyder, 1994); however, no study has been conducted to determine the effect of water management (artificially lowering water levels) on fire regimes (Wu et al., 1996).

Figure 19 and **Table 5** provide a summary of the effects of several documented peat fires in the Everglades, as well as a summary of the hydrologic conditions preceding each fire (Gleason and Stone, 1974; Zaffke, 1983; FFWCC, unpublished data). Time series hydrologic data from gauges in WCA-3A were selected for their proximity to each fire. The best available stage data for the period from January 1973 to August 1990 were analyzed to determine the depth and duration that water levels declined below ground preceding each fire.

Table 5. Location, Extent, and Antecedent Water Conditions for Documented Historical Fires within WCA-3A.

Nearest Gauge	Date of Fire	Observed Location (x's)	Observations	Max. Depth (ft)	Duration (days)
3A-3	March 1973	East of Miami Canal, north of Alligator Alley	Large areas denuded of vegetation; bedrock visible, large tree islands destroyed (Gleason and Stone, 1974)	-0.5	50
3A-4	June 1981	South of Alligator Alley, east of the Miami Canal	Peat losses average 3.6 inches, Maximum soil loss up to 11 inches (Zaffke, 1983; FFWFC personal communication, 1993)	-0.9	30
3A-11	March 1989	NW corner of WCA-3A west of Miami Canal	(FFWCC personal communication, 1993)	-0.4	30
3A-3	August 1990	East of Miami Canal, north of Alligator Alley	Damage primarily to tree islands only (FFWCC personal communication, 1993)	-1.1	Not determine d
3A-11	April 1999	NW corner of WCA-3A, west of Miami Canal	Peat losses of 4 to 6 inches, max. soil loss up to 12 in., damage to willowheads and wildlife (SFWMD, 1999)	-1.8	33

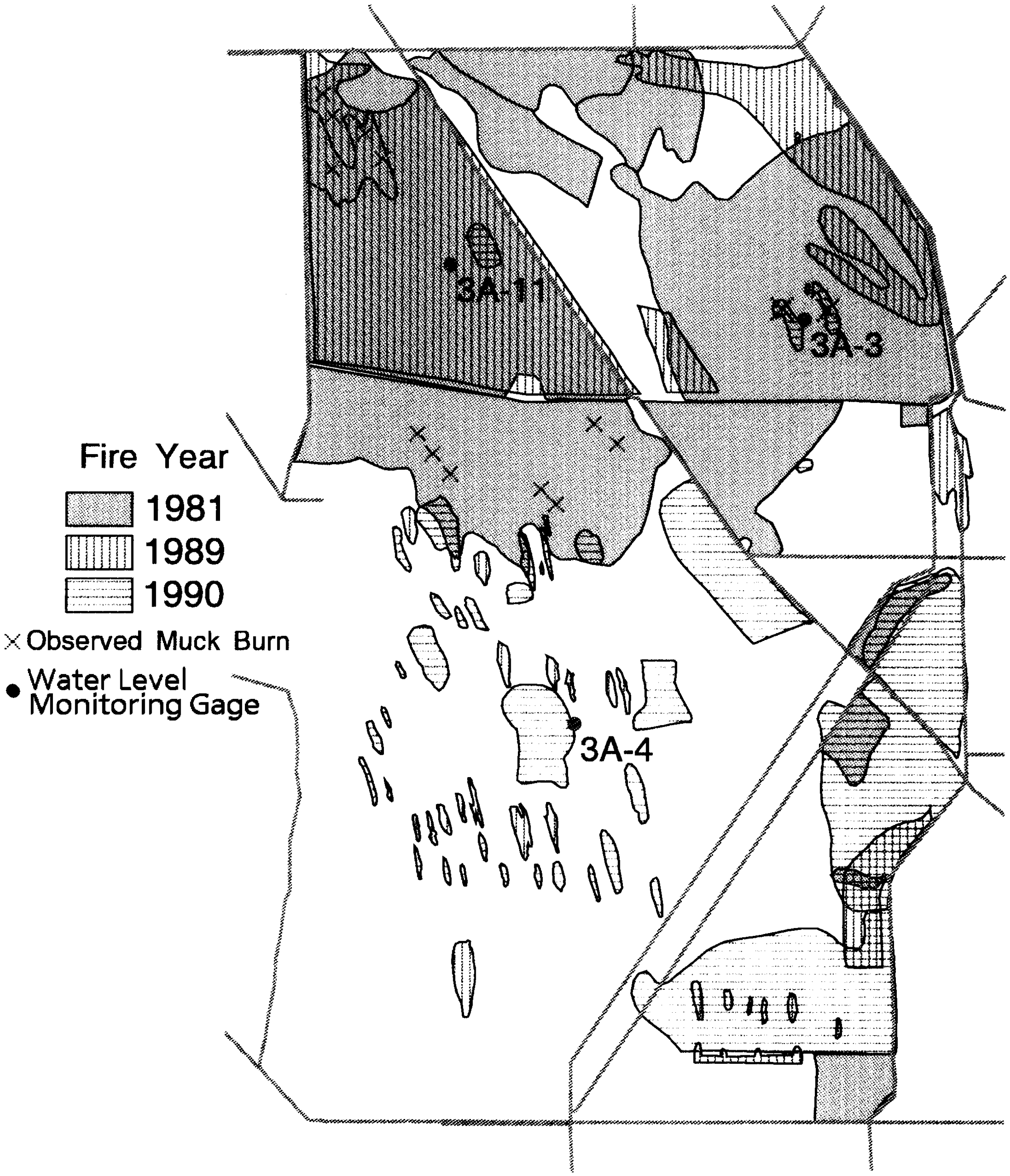

Figure 19. Location, Extent and Antecedent Water Conditions for Documented Historical Fires within WCA-3A.

Review of these data suggests that when water levels recede -0.4 to -1.8 feet below ground for a duration of 30 to 50 days, there is a significant risk that an intense fire may occur in the area, cause loss of peat soils, and impact tree islands and wetland plant communities. These results are within the range reported by Loveless (1959), who noted that “fires, which occur during normal hydroperiod cycles when water levels do not recede more than four or five inches below the surface of the ground, seemingly have little effect on dominant plant communities.” However, during extreme drought periods when water levels recede 3 to 4 feet below ground, fires not only consume the vegetation, but also destroy the upper, dry, compacted peat layers to a depth of 3 to 4 inches over large areas, and up to a foot or more in localized situations (Loveless, 1959). **Figure 19** also suggests that the amount of peat that can be consumed is related to water depth at the time of the fire. For example, during the June 1981 fire (Zaffke, 1983), the maximum amount of peat consumed was 11 inches which directly corresponds to the depth of the water table at the time of the fire (-0.9 feet or 11 inches below ground).

Water Level Criteria for the Everglades

Water Supplies for Sustaining the Everglades

The hydropattern and water quantity restoration goals for the Everglades will require a multifaceted approach, with the ultimate goal to create a sustainable ecosystem. Restoration and protection of the resource will be achieved by using the full range of options that are available to the agency, including design and construction of new facilities, water resource and water supply development projects, operation of new and existing facilities, and regulatory programs for water supplies during drought and non-drought conditions.

The resource protection framework for ensuring sufficient water supplies to sustain water resources, such as the Everglades, is depicted on **pages 7-9** of this document. This framework contemplates the use of water reservations to protect fish and wildlife; consumptive use permit criteria to protect water supplies from harm during non-drought conditions; and the use of minimum flows and levels and water shortage restrictions to manage water supplies during drought conditions by reducing the potential for significant harm and serious harm to the water resources. Each of these state water resource protection standards must be developed and implemented together to achieve the hydropattern restoration goals for the Everglades.

The Comprehensive Everglades Restoration Program (CERP) identifies projects and water supplies needed to achieve Everglades hydropattern restoration. In the CERP, the “restored” Everglades is primarily defined as the ecosystem that will exist when the completed CERP recommendations are in place in 2050, as described in Section 5.7 of the Final Integrated Feasibility Report (USACE 1999, p. 5-35). The specific hydropattern goals for the Everglades were identified as the hydrologic performance of the system in alternative “D13R” as modeled by the SFWMM (USACE 1999, Chapter 9). The D13R simulation defines Everglades water needs for the range of rainfall and drought conditions that occurred during the 31-year SFWMM calibration period.

Water Supplies for Preventing Harm -- Everglades "No Harm" Standard

Minimum flows and levels are just one of the essential components of the resource protection framework being developed for the Everglades as part of LEC planning process. In order to assure ecosystem sustainability and achieve restoration, it is also essential to define the "no harm" conditions for the Everglades. Harm under the proposed resource protection framework is considered to be changes in the hydrology that cause short term (seasonal) adverse affects to water resource functions. Water resource functions to be protected from harm are based on the Everglades ecosystem restored under the CERP, as discussed previously in this document.

As shown in **Figure 1** in Chapter 1, "no harm" levels differ from the "significant harm" minimum levels. As a result, the "no harm" water demands, which account for a specific level of protection to sustain the restored system, are established under a separate legal directive. The protection standards associated with preventing harm are higher than those identified for significant harm, or MFLs, which should only occur during more extreme drought conditions. The Lower East Coast Regional Water Supply Plan (LECRWSP) recommendations will be implemented to achieve this level of protection. The no harm standard will be implemented using the full range of options that are available to the agency as stated above. In terms of allocating water, this standard helps to define water availability for use during normal to moderately dry conditions, including a 1-in-10 level of drought. Beyond the 1-in-10 year drought conditions, the Everglades MFL and associated water shortage restrictions will be used, in part, to prevent significant harm and serious harm to the Everglades resource functions.

For purposes of the LECRWSP, which has a 20 year planning horizon, specific Everglades "no harm" standards will be derived from SFWMM simulations for the year 2020 that include implementation of the CERP projects. It is anticipated that by 2020, most of these projects will be complete, except for 50% of the Lakebelt project features (without the completed Lakebelt project, MFLs cannot be fully met in Everglades National Park). A goal of the LECRWSP is to identify water supplies available under this model scenario and tools to provide and protect required water supplies, based on the resource protection framework discussed above.

Everglades Significant Harm Standard

Most of the Everglades hydric soils lie directly above the Biscayne aquifer. Water levels observed in the Everglades (either above or below ground surface) can also be thought of as a surface expression of the Biscayne aquifer water table. Therefore, minimum water levels proposed for the Everglades are also minimum levels for the Biscayne aquifer where it underlies Everglades peat or marl soil west of the north/south perimeter levee.

Based on the information presented previously, minimum water level criteria were developed to protect Everglades soils, wetland vegetation, wildlife habitat, and regional ground water supplies by preventing the loss of hydric soils within the remaining Everglades system. Minimum criteria developed for the Everglades were designed to protect the above water resource functions by preventing the loss of hydric soils. Hydric soils (freshwater peat and marl) were selected for the following reasons:

- Peat and marl are the primary soils that characterize the Everglades. More than 90 percent of the remaining Everglades are comprised of these soils.
- Peat and marl soils sustain all of the major plant associations (sawgrass marshes, sloughs, wet prairies, and tree islands) and animal communities that characterize the Everglades.
- Review of the literature indicates that both of these soil types are reliable indicators of past hydrological/biological conditions within the Everglades.
- Sufficient data concerning historical and present day soil conditions exist that can be used as a reasonable basis for setting initial minimum water level criteria for the Everglades (Tropical BioIndustries Inc., 1990).

Figure 18 shows the spatial distribution of the major hydric soil types within the historic Everglades in relation to key water management gauges. The proposed criteria are based on the rationale that ground water drawdowns and durations greater than those recommended will cause significant harm to hydric soils and their associated Everglades vegetation and wildlife communities. The numerical values for the proposed criteria were determined based on the following:

- A review of available literature that describes the hydrologic conditions necessary to sustain hydric soils and their parent wetland plant communities within the Everglades
- Comparison with historical water levels and fire records
- Comparison with simulated water levels derived from output of the NSM 4.5 during drought years.

Definition of Terms

The proposed criteria consist of four components: a minimum water depth, duration of the event, frequency of occurrence, and potential for causing significant harm to the environment. These terms are defined below:

- <u>Minimum Water Depth</u> - The lowest water level which, if maintained for a specified period of time, is sufficient to protect Everglades water resources, soils, and plant and animal communities from significant harm during periods of deficient rainfall.
- <u>Duration</u> - The estimated period of time that water levels can remain below ground at the specified minimum water depth without causing significant harm to Everglades water resources, soils, and plant and animal communities.

- Frequency of Occurrence - The average periodicity that ground water levels recede to minimum levels over a prescribed period of time (e.g., once every five years). If minimum water level conditions recur more often than the stated criteria, the risk of significant harm to Everglades soils, vegetation, and wildlife predator/prey relationships are greatly increased.
- Significant Harm - Significant harm is defined as a loss of specific water resource functions that take multiple years to recover which result from a change in surface water or ground water hydrology. For the Everglades, adverse impacts include peat oxidation, increased frequency of severe fires, soil subsidence and loss of hydric soils; loss of dry season aquatic refugia; loss of tree island communities; long-term loss or change in wetland vegetation; and long-term loss or change in the distribution and abundance of wildlife communities. Once such changes have occurred, many years, decades or perhaps centuries may be required to restore these resources to their former condition.

Criteria for Protection of Peat Soils and Associated Wetlands

To prevent significant harm to the water resources as indicated by loss of peat soils and associated wetland plant communities, the following minimum water level criteria are proposed for the peat-forming areas of the Everglades:

Water levels within wetlands overlying organic peat soils within the WCAs, Rotenberger/Holey Land WMAs, and Shark River Slough (Everglades National Park) should not fall 1.0 feet or more below ground level for more than 30 days duration, at return frequencies not less than those shown in ***Tables 6*** *and* ***7****.*

Table 6. Minimum Flows and Levels Criteria for Organic Peat and Marl-Forming Soils Located within the Remaining Everglades.

Area	Soil Type	Depth below ground (ft.)	Duration below ground (days)	Allowable Return Frequency (years)
WCAs	Peat	1.0	30	1-in-4 to 1-in-7[a]
Holey Land and Rotenberger WMAs	Peat	1.0	30	1-in-2 to 1-in-3
Shark River Slough (Everglades National Park)	Peat	1.0	30	1-in-7 to 1-in-10
Marl-forming wetlands located within Everglades National Park	Marl	1.5	90	1-in-2 to 1-in-5

a. Return frequency depends on location relative to a specific water management gauge. See **Figure 18** and **Table 7**, for specific water management gauge locations and MFL criteria.

Table 7. Minimum Water Levels, Duration, and Return Frequencies for Key Water Management Gauges Located Within the Remaining Everglades.

Area	Key Gauge	Indicator Region[a]	Soil Type	Minimum Depth (ft) and Duration (days)	Return Frequency (years)[b]
Water Conservation Areas					
WCA-1	1-7	27	Peat	-1.0 ft >30 days	1-in-4
WCA-2A	2A-17	24	Peat	-1.0 ft >30 days	1-in-4
WCA-2B	2B-21	23	Peat	-1.0 ft >30 days	1-in-3[c]
WCA-3A North	3A-NE	21	Peat	-1.0 ft >30 days	1-in-2
WCA-3A North	3A-NW	22	Peat	-1.0 ft >30 days	1-in-4
WCA-3A North	3A-2	20	Peat	-1.0 ft >30 days	1-in-4
WCA-3A North	3A-3	68	Peat	-1.0 ft >30 days	1-in-3
WCA-3A Central	3A-4	17	Peat	-1.0 ft >30 days	1-in-4
WCA-3A South	3A-28	14	Peat	-1.0 ft >30 days	1-in-4
WCA-3B	3B-SE	16	Peat	-1.0 ft >30 days	1-in-7
Everglades Agricultural Area					
Rotenberger WMA	Rotts	28	Peat	-1.0 ft >30 days	1-in-2
Holey Land WMA	HoleyG	29	Peat	-1.0 ft >30 days	1-in-3
Everglades National Park					
NE Shark River Slough	NESRS-2	11	Peat	-1.0 ft >30 days	1-in-10
Central Shark River Slough	NP-33	10	Peat	-1.0 ft >30 days	1-in-10
Central Shark River Slough	NP 36	9	Peat	-1.0 ft >30 days	1-in-7
Marl wetlands east of Shark River Slough	NP-38	70	Marl	-1.5 ft >90 days	1-in-3[d]
Marl wetlands west of Shark River Slough	NP-201 G-620	12	Marl	-1.5 ft >90 days	1-in-5
Rockland marl marsh	G-1502	8	Marl	-1.5 ft >90 days	1-in-2[d]
Taylor Slough	NP-67	1	Marl	-1.5 ft >90 days	1-in-2[d]

a. Indicator regions are groupings of model grid cells within the SFWMM consisting of similar vegetation cover and soil type. These larger grouping of cells were developed to reduce the uncertainty of evaluating results from a single 2 x 2 square mile grid cell that represents a single water management gauge. Figure F-2 in Appendix F provides the location of each indicator region.

b. Return frequencies for peat based wetlands located within the WCAs were based largely on output of the NSM 4.5. Return frequencies for marl wetlands located in Everglades National Park were based on model results, expert opinion and consideration of management targets developed for the Comprehensive Everglades Restoration Plan (CERP).

c. Expert opinion of District staff, and results from the NSM concur, that a 1-in-6 return frequency is needed to protect the peat soils of this region from significant harm. District staff recognizes that this value had to be modified to account for consideration of changes and structural alterations that have occurred to the hydrology of WCA-2B. Model results of the CERP and LEC water supply planning process suggest full restoration of WCA-2B may not be possible. A policy decision was made to present a MFL return frequency of 1-in-3 in this table to reflect conditions that can be practically achieved.

d. These return frequencies represent the expert opinion of District staff based on "agreed upon" management targets developed in the CERP and LEC planning processes, and output of the NSM. It is the expert opinion of ENP staff that NSM does not properly simulate hydrologic conditions within the Rockland marl marsh and Taylor Slough and the proposed return frequencies listed above may not necessarily protect these marl-forming wetlands from significant harm. They propose that a frequency of 1-in-5 is necessary to prevent significant harm from occurring to these unique areas of the National Park.

Criteria for Protection of Marl Soils and Associated Wetlands

Marl-forming wetlands occur primarily within Everglades National Park (**Figure 18**). The District will work with the National Park Service to define criteria that will protect specific areas and resources within Everglades National Park. Based on the examination of available data, the following criteria were developed to protect marl wetland communities within Everglades National Park:

Water levels within marl-forming wetlands that are located east and west of Shark River Slough, the Rocky Glades, and Taylor Slough within Everglades National Park should not fall more than 1.5 feet below ground level for more than 90 days at return frequencies not less than those shown in ***Tables 6*** *and* ***7****.*

Impacts of Failure to Meet Proposed Criteria.

The following impacts can be expected to occur if the proposed criteria are exceeded:

- Reversal of the natural process of peat accretion and an increase in the rate of soil oxidation and soil subsidence (lowering of ground level elevations), which reduce the long-term sustainability of the Everglades ecosystem
- Reduced wetland aquatic productivity, disruption of food chains, loss of dry season aquatic refugia, shifts in wetland vegetation from wet-adapted species to those more tolerant of drier conditions, and invasion by exotic species such as melaleuca
- Increased frequency of severe fires that consume peat, damage tree islands, expose bedrock, lower ground level elevations, and destroy wildlife habitat that supports rare, threatened, or endangered species
- Continued loss of peat resources and associated freshwater head within the Everglades Protection Area, which has the potential to reduce the water storage capacity of the regional ecosystem and increase the threat of saltwater intrusion during droughts

Considerations that may Affect Everglades Minimum Levels

In defining significant harm for an area, the Governing Board is required to consider changes and structural alterations to the hydrologic system as discussed in the section of this report entitled, *Identification of Baseline Conditions for Water Resource Functions* (**page 38**). The CERP recognized that in certain portions of the Everglades the hydrologic system cannot be fully restored due to changes and structural alterations that exist. The governing board in reviewing the proposed minimum levels for the Everglades may determine that for such areas, where full restoration may not be possible or desirable, the minimum level should be adjusted accordingly. District staff will be analyzing the performance of the CERP restoration alternative to determine locations in the Everglades hydrologic system where the proposed minimum levels are not met as a result of operational changes and structural alterations when all recommended components of the plan are in place. In such areas, the Governing Board may find it necessary to reassess the proposed minimum level to account for these shortfalls in the restored hydrologic system. This determination will be reflected in the final draft of this document.

BISCAYNE AQUIFER

Resource Functions

Water management criteria need to be established that will protect the water resource functions of the Biscayne aquifer. The following water resource functions were considered in the development of minimum water level criteria for the Biscayne aquifer:

- The Biscayne aquifer represents the primary source of water supply for urban and agricultural users within the LEC Planning Area.
- For this reason, ground water levels within the Biscayne aquifer should be maintained at sufficient levels to prevent saltwater intrusion. The highest risk for saltwater intrusion occurs during periods of seasonally high water demands and low rainfall.
- The Biscayne aquifer also provides base flow to important estuaries such as the Lake Worth Lagoon, Biscayne Bay, and Florida Bay during low rainfall years.

Under present operating conditions, cutbacks in water use by individual utilities in localized areas may be required during drought conditions. The District's goal through its planning, water resource development and water supply development efforts is to provide sufficient water so that significant cutbacks occur no more often than once every 10 years (i.e. a 1-in-10 year level of certainty). Decisions to restrict water use for individual utilities were historically based on chloride concentrations in monitoring and production wells.

Minimum operational water levels for the coastal canals are proposed in this report, recognizing that water levels in the canals are directly related to water levels in the aquifer system adjacent to these canals, but only indirectly related to chloride levels in saltwater intrusion monitoring wells. The proposed minimum operational canal levels will be used by the District, other agencies and local interests as regional indicators that saltwater intrusion may become a problem if water levels remain below these levels for more than 180 days duration. In such cases, a regional response would occur, such as providing additional releases to coastal canals from the regional system. Development of minimum water level criteria for the canals as a means to protect the aquifer from significant harm should not change the application of existing drought management methods and criteria that affect operation of individual wellfields.

Technical Relationships Considered in Defining Significant Harm

Saltwater intrusion poses a continuing threat to the Biscayne aquifer. In order to restrict the inland migration of the saline interface, a sufficient freshwater head must be consistently maintained within the aquifer. Inadequate water levels occurred in 1939, when more than 10,000 water supply wells in South Florida were affected by high chloride concentrations, including the partial loss of five major wellfields (Parker et al., 1955). Since that time, a number of different actions have been taken to protect public and private wellfields from the threat of saltwater intrusion. Coastal water control structures were completed in the 1950's, monitoring efforts have significantly improved and the SFWMD Consumptive Use Permitting program has been established.

Definitions of Harm and Significant Harm

The water resource protection framework to sustain the Biscayne aquifer is based on the conceptual model shown in **Figure 1** in Chapter 1 of this document. As discussed herein, protection of the Biscayne aquifer is based on the aquifer's function as a water supply source. As a result, the definitions of harm and significant harm to this function are based on the extent of movement of the saltwater interface into the vicinity of, and eventually into existing and future water supplies.

Biscayne Aquifer -- No Harm Standard

Harm to the Biscayne Aquifer in terms of saltwater intrusion is considered to be movement of the saltwater interface to a greater distance inland than has occurred historically as a consequence of seasonal water level fluctuations up to and including a 1-in-10 year drought event.

In order to prevent harmful movement of the saltwater interface in the Biscayne aquifer, the District manages coastal ground water levels by operating the primary canal network, regulating surface water control elevations for developments (through surface water management permitting) and by limiting coastal consumptive use withdrawals. Operational criteria for the coastal canals that are maintained by the District to prevent harm are shown as the "Control Levels" on **Table 8**. These management levels vary seasonally as the District works to balance the goals of flood protection (wet season control level) and water supply (drought management control level). The drought management control levels represent target management elevations during the dry season. Water supply releases are made from regional storage sources (WCAs, Lake Okeechobee) to achieve these targets whenever possible. These canal levels in turn influence the adjacent dry season ground water elevations within the Biscayne Aquifer.

The consumptive use permit conditions for the protection of coastal fresh ground water dovetail with these canal operational levels by requiring coastal users to maintain a groundwater divide between the withdrawal point and the source of saline water. This is described as follows in the SFWMD Basis of Review document, Volume III, p A-37 (SFWMD, 1994b):

Table 8. Recommended Minimum Canal Operational Levels for the Biscayne Aquifer.

Canal/Structure	Wet Season Control Level (ft NGVD)	Average Canal Level (ft NGVD)	Drought Management Control Level (ft NGVD)	Proposed Minimum Canal Operational Levels Needed to Protect Against MFL[a] Violations During Drought Conditions (ft NGVD)
C-51/S-155	8.50	8.12	7.80	7.80
C-16/S-41	8.20	8.23	7.80	7.80
C-15/S-40	8.20	8.39	7.80	7.80
Hillsboro/G-56	7.70	7.43	6.75	6.75
C-14/S-37B	7.20	6.82	6.50	6.50
C-13/S-36	5.60	4.43	4.00[b]	3.80
North New River/ G-54	4.00	3.68	3.50	3.50
C-9/S-29	3.00	2.16	1.80	2.00
C-6/S-26	4.40	2.55	2.50[b]	2.00
C-4/S-25B	4.40	2.55	2.50[b]	2.20
C-2/S-22	3.50	2.86	2.50[b]	2.20

a. Duration Criterion - water levels within the above canals may fall below the proposed minimum canal level for a period of no more than 180 days per year.

b. These levels will be maintained if sufficient water is available

"Cumulative withdrawals from a fresh water aquifer may only occur in such manner that a hydraulic barrier between the withdrawal facility or facilities and the source of saline water is maintained. This is accomplished through the maintenance of a fresh water mound or ground water divide in the aquifer located between the source of saline water and the point of withdrawal at all times of the year. Staff will not recommend a newly proposed use for approval or an increase in allocation for an existing use under the following circumstances:

A. The hydraulic gradient between the wellfield and saline water is such that a hydraulic gradient (mound of fresh water) less than one foot National Geodetic Vertical Datum (NGVD) exists between the wellfield and saline water source during the months of November through April

B. Monitoring wells within 800 feet of a production well reflect chloride concentration increases at the base of the aquifer, indicating long term advancement of the saline front toward the wellfield or within the fresh water portions of the aquifer

C. Other evidence shows saline water intrusion will be a serious threat to the wellfield and natural resource if pumpage is allowed or increased

Withdrawals of fresh water must not result in significant upconing of saline water. Significant movement is defined as a movement of one-third of the original distance separating the bottom of the screened or open interval of a production well from the boundary of saline water below it."

These two programs (canal operations and consumptive use permitting), implemented as described above, have been successful in preventing harmful movement of saltwater within the Biscayne aquifer, except for some very localized events in areas where the saltwater interface has not been stable. Studies show that movements of saltwater in these areas were most likely the result of drainage associated with land development activities and surface water management systems (Merritt, 1996).

Biscayne Aquifer Significant Harm Standard

Significant harm occurs to the Biscayne aquifer when coastal saline groundwater moves inland to an extent that it actively limits the ability of consumptive users to develop fresh groundwater in the amounts specified in existing and future consumptive use permits and will require several years for the freshwater source to recover for use.

These extreme conditions would be determined on a localized scale, based on measured water quality and water level data which document the actual extent and movement of saltwater. These conditions are projected to occur, pursuant to the resource protection framework shown in **Figure 1** in Chapter 1, under drought conditions that exceed the 1-in-10 year level of certainty associated with the consumptive use permit program. In cases where the potential for significant harm exists, permitted allocations may be restricted under a District water shortage order to prevent further inland movement of saltwater that could cause serious harm to the water resource. These restrictions are imposed in phases (**Figure 1** in Chapter 1), which require more severe withdrawal cutbacks with increasing potential for harm, or inland movement of the saltwater front.

Once the determination has been made that the saltwater front has moved inland and potentially may limit existing and future withdrawals (i.e. cause significant harm), phase three water shortages would be imposed on consumptive users. Under these conditions, it has been the policy of the District to require a level of withdrawal cutbacks that could potentially cause economic losses to consumptive users.

Relationship Between Canal and Ground Water Levels and Saltwater Intrusion.

The District tried several approaches to determine if a relationship exists between groundwater fluctuations and saltwater movement. The following is a discussion of that evaluation.

Review of Previous Studies

Loss of the freshwater mound that previously existed behind the coastal ridge system is generally regarded as one of the major causes of saltwater intrusion within South

Florida (Parker et al., 1955; Fish and Stewart, 1991). Prior to the development and drainage of South Florida, a large freshwater mound formed behind the Atlantic Coastal ridge during the rainy season. Ground water flows seaward were so large that boils or freshwater springs occurred off the coast and were used by early mariners to replenish their ship's stores with fresh water.

The ground water hydrology of the LEC Planning Area has been permanently altered by urban and agricultural development and construction of the C&SF Project. Construction of a series of canals has drained both the upper portion of the Biscayne aquifer and the freshwater mound behind the coastal ridge. This has resulted in a significant decline in ground water flow towards the ocean and, consequently, has allowed the inland migration of the saline interface during dry periods. Large coastal wellfields have also been responsible for localized saltwater intrusion problems. Construction of coastal canal water control structures, beginning in the 1940s, has helped to stabilize or slow the advance of the saline interface, although isolated areas still show evidence of continued inland migration of salt water.

An example of the effect of saltwater intrusion over time is shown in the 1904 map of Miami-Dade County (**Figure 20**), which indicates the condition of the area prior to the construction of major drainage projects. As drainage systems were built, ground water elevations were reduced and seawater moved landward principally along the major canals systems. By 1953, several saltwater control structures had been built in order to control the inland extension of seawater. By 1962, the system had stabilized with significant rollback of the freshwater-saltwater interface along the Little River and Biscayne canals. Significant regional droughts occurred in 1971, 1981, 1985, and 1990. The effects of recovery are shown in the more recent 1984 and 1995 maps (**Figure 20**). Comparison of the 1984 map with recent data from 1995 indicates that conditions remain relatively stable and in some areas the line has moved further seaward (Fernald and Purdum, 1998).

Saltwater intrusion of the Biscayne aquifer continues to be a threat today. Severe droughts, such as in 1981, resulted in widespread inland movement of the saline interface. In 1987, the city of Hallandale permanently reduced total pumpage by 50 percent and shut down their primary wellfield (SFWMD, 1993b). Koszalka (1995) reports that the saline interface moved inland in Broward County between 1980 and 1990 due to the lowering of regional ground water levels and increased pumpage. Sonenshein and Koszalka (1995) report similar situations in central and southern Miami-Dade County. Recent monitoring data from Coral Gables, Hallandale, Pompano Beach, southern Martin County, and Boca Raton show that the saltwater front continues to advance inland (Lietz et al., 1995).

Work conducted at Cutler Ridge in South Miami-Dade County indicates that the saltwater front is dynamic and not static as originally assumed (Kohout, 1960). In addition, the observed actual position of the saline interface is several miles seaward of the position calculated using the Ghyben-Herzberg relationship (GHR) (see GHR discussions in Chapter 3 and below). Kohout (1960) observed that as salt water moved inland, a significant portion of the diluted sea water was circulated back toward the sea along the zone of diffusion. It is estimated that up to 20 percent of the salt water that intrudes the aquifer is returned to seawater, with the remaining 80 percent being retained in the aquifer

Figure 20. Historical Extent of Saltwater Intrusion at the Base of the Biscayne Aquifer in the Greater Miami Area (from: Fernald and Purdum, 1998).

(Kohout, 1960). This cyclic flow acts, in part, as a deterrent to further saltwater intrusion since a percentage of the salt water is returned to the sea.

The city of Hallandale, in southeastern Broward County, is an area that continues to be susceptible to saltwater intrusion. A series of monitoring wells located perpendicular to the coast have recorded the inland migration of the saline interface for more than 25 years. Evaluation of the data suggests that the saltwater front has consistently migrated inland at a rate of approximately 80 feet per year. Andersen et al. (1988) conducted a detailed evaluation of the saltwater interface in the vicinity of Hallandale using a coupled, flow/solute transport, three-dimensional finite element model. They evaluated several potential causes for continued saltwater intrusion, including wellfield pumpage, rainfall deficiencies, and lowering of inland canal stages due to urbanization. Although their model could not localize the cause of saltwater intrusion, their results demonstrated the sensitivity of ground water stages for maintaining the saline interface. These modeling studies also indicated that lowering inland canal stages by only several tenths of a foot could result in widespread movement of the saline interface. In addition, a significant lag time exists between the lowering of the hydraulic head and the subsequent movement of the saline interface (Andersen et al., 1988).

Merritt (1996) also conducted a detailed assessment of saltwater intrusion in southern Broward County. Analysis of monitoring well data from the period from 1945 to 1993 indicated that the front had migrated inland up to one half mile in some areas. Merritt (1996) then developed a cross-sectional model of southeastern Broward County to simulate movement of the saltwater interface, using both a sharp interface and diffusion model code. An important result from his work is that the position of the saline interface may vary seasonally but its long-term position is governed by average annual or long-term ground water levels rather than by seasonal fluctuations.

Review of Water Level and Monitoring Data

Regional water level monitor data show a close relationship between the water level stages maintained in the District's primary canals and groundwater elevations within the Biscayne aquifer. This is particularly true in south Broward and Miami-Dade counties where permeability of the Biscayne aquifer is very high. However, the relationship between surface water level fluctuations and the movement of the salt water interface is poorly understood for the Biscayne aquifer at this time. As a result, it is difficult to conclusively determine what canal stages would result in significantly harmful movement of salt water along the coastal margin of the Biscayne aquifer.

Ghyben-Herzberg Relationship

On a conceptual level, one of the first approaches District staff used to estimate a minimum level that would prevent saltwater intrusion of the aquifer was the Ghyben-Herzberg relationship (The GHR). This well-established principle examines the density differences between fresh water and salt water at equilibrium. For each 40 feet of aquifer thickness, a freshwater head of one foot is required to maintain or stabilize the saltwater front under static conditions. The equation derived to explain this relationship is known as the GHR named in honor of the two scientists who independently discovered this principle in the late 1800s-early 1900s. Application of the GHR provides a conservative estimate of the location of the saltwater interface, assuming hydrostatic conditions in a homogenous, unconfined coastal aquifer.

The aquifer system along Florida’s southeast coast ranges in thickness from approximately 100 to 300 feet. Therefore, to ensure that saltwater intrusion does not occur within these aquifer systems, a freshwater head of between 2.5 and 7.5 ft NGVD would theoretically be needed to maintain or stabilize the saltwater front based on the GHR.

Although the GHR can provide an initial estimate of the minimum level needed to prevent saltwater intrusion under static conditions, actual field observations indicate that the equation may over estimate the required freshwater head in systems showing fluid flow (Freeze and Cherry, 1979). This over estimation may be due in part, to the heterogeneous aquifer characteristics associated with the surficial aquifer system, horizontal and vertical flow components, and the transient nature of the saltwater interface. District staff utilized this conservative approach to determine the theoretical position of the saline interface within the Biscayne aquifer as compared to its actual position (**Figure 21**) and to provide a means of comparison to other statistical approaches developed by District staff to determine minimum freshwater heads that should be maintained to protect the aquifer.

For comparison purposes, the GHR was analyzed to determine its ability to stabilize the saltwater interface. The relationship considers water levels, density differences of salt water and fresh water, and thickness of the aquifer to determine the distance to the saltwater interface. The depth to the base of the Biscayne aquifer in Miami-Dade, Broward and Palm Beach counties was determined from existing hydrogeologic work conducted by Fish (1988), Fish and Stewart (1991), and Shine et al. (1989). Results of these analyses indicate that the actual position of the saline interface is seaward of the theoretically calculated location. This relationship is shown in **Figure 21**. These data suggest that the GHR provides a relatively conservative estimate of the required freshwater head necessary to stabilize the saltwater interface and supports Kohout's (1960) work, which reported that up to 20 percent of saline water that intrudes the Biscayne aquifer is returned to sea along the seepage face. Details of these analyses may be found in **Appendix A** of this report.

It should be emphasized that District staff did not use the GHR to develop any minimum level recommended in this report. Its use in this report is for comparison purposes only.

Aquifer Water Level/Water Quality Relationships

In addition to the Ghyben-Herzberg analysis, staff conducted a review and analysis of water level and water quality data from more than 500 wells located within the LEC Planning Area. Water level and water quality data collected from these wells were analyzed to determine if a statistical relationship exists between water levels, duration of low water level events and subsequent movement of the saltwater interface in response to low water events. Water level data from each well was evaluated to determine average dry season and wet season levels as well as long-term trends. Chloride concentrations were also examined to determine whether or not the saltwater front had reached a particular well, appeared to be stable, and/or appeared to be either moving inland or retreating seaward. In addition, stage duration curves were developed for each coastal water control structure to determine mean (50th percentile) and standard deviation (84th percentile) water levels at each salinity control structure. These data are presented in detail in **Appendix A**.

In addition to the above effort, detailed statistical analyses were performed on 49 monitoring wells in Broward County to investigate the correlation between observed chloride concentration and water table elevation. Each monitoring well was classified based upon its distance to the coast and its geographical location. Water levels were converted to equivalent freshwater heads to account for the denser salt water contained in some wells. These data are provided in **Table A-1** of this report. Results of these analyses

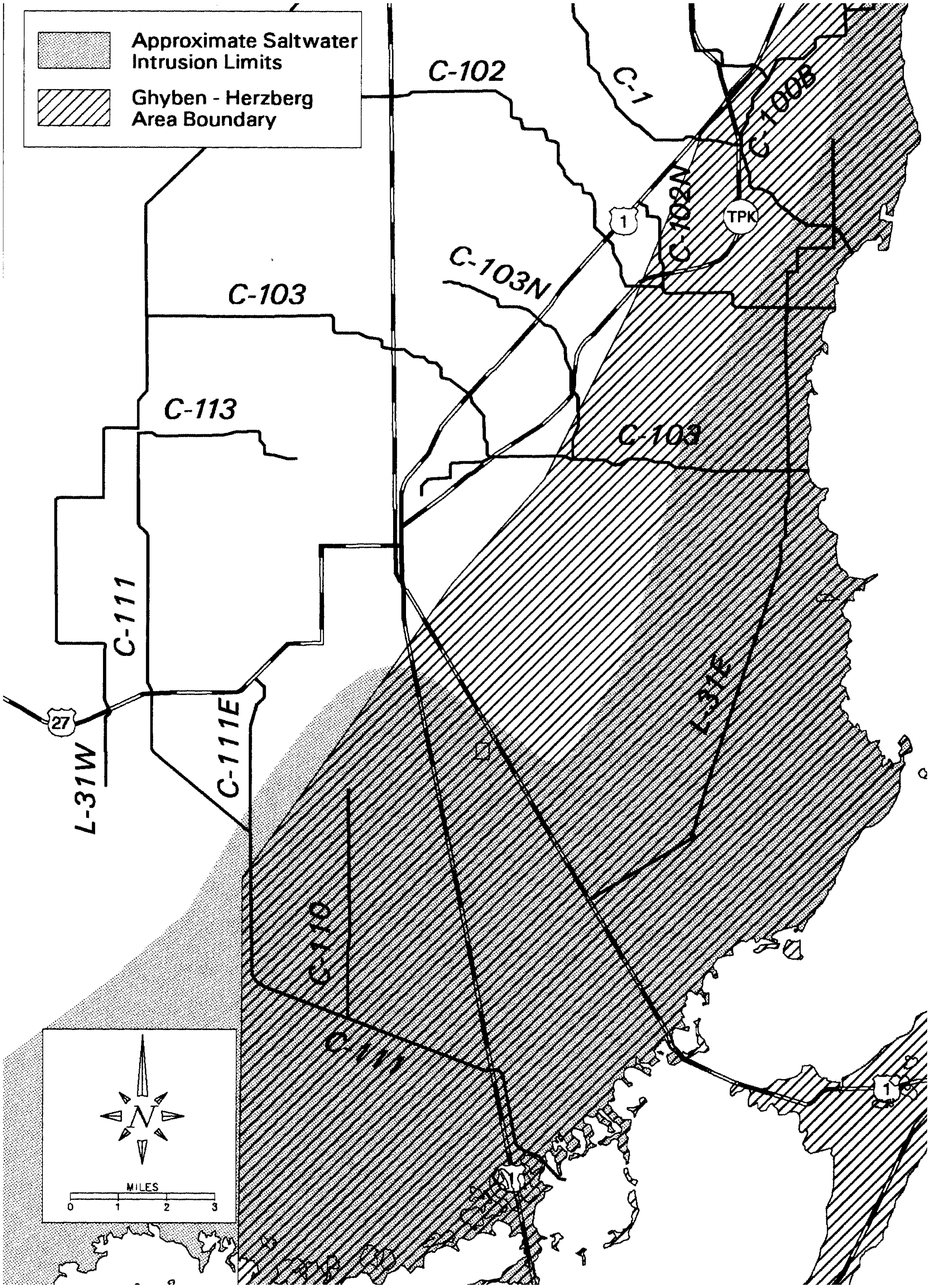

Figure 21. Theoretical and Actual Position of the Saline Interface Based on the Ghyben-Herzberg Relationship in the Biscayne Aquifer Located in Miami-Dade, Broward, and Palm Beach Counties.

indicate that no significant correlation of chloride concentration to freshwater head was observed for the Broward County wells.

In contrast, there does appear to be some correlation between the duration of low water periods and seasonal versus permanent movement of the saltwater interface. For example, at monitoring well G-1179, average annual water levels in 1985 were depressed for a period of four months resulting in a noticeable movement of the saline interface. The saltwater front retreated back to its former position after water levels had recovered during the following year. However, in 1989-1990, when average annual water levels were depressed for an extended period of time, the saltwater front moved inland and did not return to its previous position. These observations support the numerical simulations conducted by Merritt (1996), which show that short-term water level fluctuations do not result in long-term movement of the saltwater interface. However, preliminary interpretation of best available data suggests that movement of the interface, which occurs when water levels are depressed for more than six months, may take more than five years to recover, if recovery occurs at all, thus affecting the average chloride concentration at that location.

As discussed above and in Chapter 3, based on analysis of 500 monitoring wells, little or no saltwater intrusion occurred in areas where canal stages were maintained within one standard deviation of the mean. While the relationship between canal water levels and significant saltwater intrusion is not known, establishing a no movement/no harm criterion as an operational standard for the Biscayne aquifer appears prudent. This criterion may be revisited after further research is conducted to better define the relationship between canal stage and the movement of saltwater in the aquifer.

Review of historical water level and water quality information collected from over 500 wells located within the LEC Planning Area showed that the relationship between chloride concentrations and water levels were not as strongly correlated as might have been expected. In general, the higher the water level, the less likely that salt water was present in the well. However, even when freshwater levels were in excess of five ft NGVD, six percent of the observations showed chloride concentrations in excess of 1,000 parts per million. In addition, when water levels were below sea level, only 41 percent of the readings had chloride concentrations in excess of 1,000 ppm. Results of these analyses are presented in **Table A-2**.

Another method used to establish the freshwater-saltwater interface was the review and analysis of chloride and water level data from approximately 200 long-term monitoring wells located within the LEC Planning Area. Average dry and wet season water levels and average chloride concentrations were calculated for each well over time and well depths were recorded. Individual data from each monitoring well are presented in **Appendix A**. Analyses of these data indicate that when water levels were maintained at, or above, the level calculated by the GHR, approximately 95 percent of the wells showed no significant saltwater intrusion. However, more than 40 percent of the wells that had water levels below those specified by the GHR indicated some form of saltwater intrusion.

Temporal Relationship between Ground Water Levels and Saltwater Movement

Best available information indicates that the position of the saline interface is dependent upon average annual ground water levels. This hypothesis is supported by the modeling work of Andersen et al. (1986, 1988) and Merritt (1996) as well as the results of this study. These studies indicate that short-term variations in ground water levels may result in temporary movement of the saline interface, but the interface retreats to its former position once ground water levels return to their normal range. Furthermore, prolonged, depressed ground water levels may result in significant and permanent movement of the interface even after these water levels have returned to normal or above normal conditions. To illustrate this point, **Figure 22** provides a schematic diagram that shows the movement and retreat of the saline interface under various low water conditions.

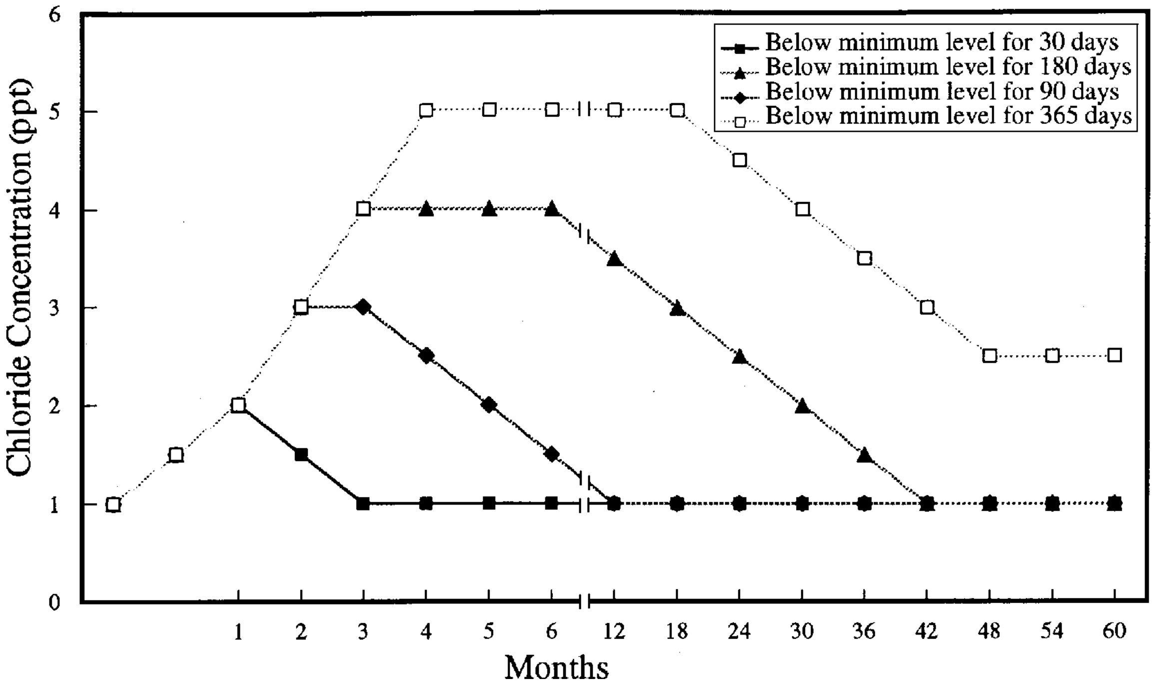

Figure 22. Schematic Illustration of the Potential Effects of the Duration of Below Minimum Water Levels and the Time Required for Chloride Concentrations to Recover in the Biscayne Aquifer. (This illustration was estimated from a review of historical data.)

As shown in **Figure 22**, it is anticipated that ground water levels can be depressed for periods of up to 180 days per year and the saline interface will retreat to its previous position, although it may take from several months to several years of average rainfall conditions for this recovery to occur. When ground water levels are depressed for periods in excess of six months duration, movement of the saline interface could take multiple (more than five) years to retreat, as shown in **Figure 22**. It is proposed that this relationship should be used as the basis to establish a minimum canal operation level and duration component for protection of the Biscayne aquifer until such time that better information becomes available. Such new information might apply detailed transient solute transport modeling and site specific ground water monitoring of the Biscayne aquifer to refine the proposed minimum ground water duration component.

Support for the six month duration component comes from several other sources. During the 1989-1990 drought, canal stages fell below the recommended minimum level for more than six consecutive months at several coastal structures. Of particular interest was central Miami-Dade County, where water levels in the C-2 and C-4 canals were allowed to fall below 2.5 ft NGVD for a period of seven months. Within approximately one year of this event, two monitor wells in the vicinity of the C-2 canal recorded significant movement of the saline interface (wells G-901 and G-432) and these wells have not yet recovered after seven years. A similar situation may have also occurred in south Palm Beach County, where depressed water levels were noted at the S-40 Structure and the adjacent E-4 Canal during 1989-1990. Noticeable movement of the interface was observed within several years of this event at two monitor wells in reasonably close proximity to the structure. Those observations suggest a relationship between the movement of the saline interface and canal stages, and also imply a duration component that is consistent with the six-month period proposed above.

Relationship between Coastal Canal Stages and Saltwater Intrusion

Regional Modeling. The SFWMD maintains the coastal canal network to provide drainage for agricultural and urbanized areas during rainfall events and recharge local ground water resources during periods of drought. In setting a minimum canal operational level to prevent saltwater intrusion of the Biscayne aquifer, it was necessary to evaluate the effect of the primary canal network on water levels within the Biscayne aquifer. To increase our understanding of this relationship, two separate model simulations were executed using the South Florida Water Management Model (SFWMM):

1. In the first simulation, the system was operated under present conditions. Coastal canals were maintained by the regional system during drought periods, and continued to receive water from the WCA system and Lake Okeechobee during low rainfall years.
2. In the second simulation, coastal canals were not maintained for water supply purposes during drought years. District operations incorporated into the model run did not attempt to maintain dry season water levels in the coastal canals.

Results of the two simulations described above were compared at 20 key monitoring locations. **Table A-3** provides a summary of these results. When the coastal canals were not maintained during dry periods, there was an increase in the number of days that coastal ground water levels fell below 1 ft NGVD. The threat of saltwater intrusion significantly increased. When coastal water levels were below 1 ft NGVD for longer periods of time, a reverse gradient developed as coastal aquifer water levels fell near or below sea level. Denser salt water from the ocean could then move inland into the freshwater portions of the aquifer. Results of these simulations indicate, that for most areas, coastal water levels appear to be highly influenced by water levels in the regional canal network. Water levels in the coastal canals largely govern the expected inland extent of the saline interface. Managing coastal canals at appropriate water levels during drought periods provides a means to stabilize the saltwater interface and restrict inland migration of the saltwater front. **Appendix A** provides a detailed summary of results of these simulations for north, central, and south Palm Beach County, Broward County, and Miami-Dade County.

Evaluation of Coastal Canal Stages. Since coastal canals are used to help control aquifer levels along the lower east coast of Florida, an evaluation of canal stage levels was necessary. Upstream canal water levels from eleven primary canals were obtained from historical records. Daily stages, where available, were obtained from each structure for the period from 1980 to the present. Structures in south Miami-Dade County were not included in this evaluation due to the uncertainty associated with developing minimum flows for Biscayne Bay and Florida Bay. Hydrographs and stage duration plots for each structure were developed for the same time frame and are provided in **Appendix B.** The mean stage (50th percentile) and the 84th percentile stage for each primary canal and water management structure are presented in **Table 8**. The 84th percentile statistically represents one standard deviation from the mean. Also included in **Table 9** are the canal maintenance levels used by the District, as simulated in the SFWMM.

Table 9. Stages at Key Water Management Structures within the LEC Planning Areas (Stages are in ft NGVD).

Canal/Water Management Structure	Mean or 50th percentile Stage (ft NGVD)	84th Percentile[a] (ft NGVD)	Canal Stages Maintained by SFWMD[b] (ft NGVD)
C-51/S-155	8.12	7.74	7.80
C-16/S-41	8.23	7.72	7.80
C-15/S-40	8.39	7.59	7.80
Hillsboro Canal/G-56	7.43	6.75	6.75
C-14/S-37B	6.82	6.60	6.50
C-13/S-36	4.43	4.15	3.80
North New River/G-54	3.68	3.28	3.50
C-9/S-29	2.16	1.90	1.80
C-6/S-26	2.55	2.07	2.00
C-4/S-25B	2.55	1.95	2.20
C-2/S-22	2.86	2.04	2.20

a. 84th percentile represents one standard deviation from the mean.

b. Canal stages maintained by the District at specific canals as simulated by the SFWMM.

The levels used in the SFWMM represent the average water level at each structure, during times when water supply deliveries were made, as determined from an evaluation of historical canal stages. When simulated canal stages fall below this level, the SFWMM imports water into the canal from the WCAs or Lake Okeechobee.

The model simulations results show a general decline in coastal canal levels maintained by the District from north to south, due primarily differences in the topography between these two areas. With the exception of the Coastal Ridge, ground elevations decrease from 15-20 ft NGVD in Palm Beach County, to less than 5 ft NGVD in parts of southwest Broward County and Miami-Dade County. Local canal levels must be maintained below adjacent ground elevations to prevent urban and agricultural flooding.

Localized Saltwater Intrusion Modeling. The final approach used to investigate the relationship between canal water levels and movement of the saline interface was the application of an existing saltwater intrusion model to study three simulated conditions. The model code utilized was the SWICHA model, a finite element solute transport/flow model developed by Andersen et al. (1986). This two-dimensional cross-sectional model was slightly modified to allow various simulations at five idealized transects located along the southeast coast of Florida. These models simulate steady-state conditions and therefore do not address temporal variations in water levels that may occur seasonally, monthly or daily within the system. The five transects (or slices) through the aquifer included south-central Palm Beach County, northeastern Broward County, central Broward County, southeastern Broward County, and north-central Miami-Dade County. The model was run using the following three scenarios at each transect to simulate various canal maintenance operations:

- Setting the minimum canal level based on the mean stage or 50th percentile level, based on historical data.
- Setting the minimum canal level based on the 84th percentile (one standard deviation from the mean) level, based on historical data.
- For comparison purposes, setting the minimum canal stage based on the theoretical GHR.

The models were used to evaluate the position of the salt water interface for various canal levels. The models simulate a transect or slice through the aquifer. The eastern edge of the model simulation is the Atlantic Ocean and the western edge is the District's primary canal. Three separate runs were made to evaluate the predicted position of the salt water interface for each of the canal levels (mean, dry season, and GHR). The models were run under dry season steady state conditions. The position of the interface predicted for each of the model runs was then compared to the actual present day position of the interface. The scenario that closely matched the present day position of the interface was then used to derive the proposed minimum operational canal level.

The basis for this approach is that selection of a canal level that moved the interface seaward would represent a recovery situation. Likewise, choosing a canal level that allowed additional landward movement of the interface could potentially result in long term movement of the interface (significant harm). If movement continued unabated, it could eventually cause a permanent shift in the interface (serious harm). It should be noted that this approach assumes that the harm and significant harm standards are nearly identical in terms of maintaining canal levels, but differ in the time period (duration) that the minimum canal operational level is exceeded.

Results of the three SWICHA model simulations and accompanying stage duration curves are presented in detail in **Appendix A**. Model results showed historical water levels that ranged between the mean (50th percentile) and one standard deviation from the mean (84th percentile) for each of the five transects modeled represented the most appropriate levels that would restrict movement of the saline interface without adversely affecting flood control. These data represented the closest fit to establish canal operational levels that prevent further inland saltwater movement, for each of the five tranects modeled.

The canal water levels that are equivalent to the 84th percentile (**Table 8**) correlate well with the drought management control levels maintained by the District (**Table 9**). These drought management control elevation targets for the coastal structures have been in place for decades. Review of historic saltwater intrusion and canal stage records show two noteworthy conclusions:

- The saltwater interface appears to have been generally stable in the groundwater aquifer adjacent to these structures (a possible exception occurs in well G-432, located in the C-4 canal basin Miami/Dade County, where chloride levels increased in 1989-90 and remained elevated); and
- During the dry season, there are a number of days when the canal stages drop below the target management levels without measurable saltwater movement.

In summary, the model simulations showed no apparent correlation between canal water levels and movement of the saltwater interface. In addition, several other important factors were observed:

- Water levels along coastal Miami-Dade, Broward, and Palm Beach counties are largely controlled by the District's primary canal system. Regionally, these canal systems control the position of the saltwater interface.
- Results of these simulations indicate that on a regional scale, the position of the saltwater interface can be regulated by management of water levels in the District's canal system. Localized saltwater intrusion problems still need to be addressed through detailed investigations and permitting.
- The ability to manipulate canal water levels as a means to control saltwater intrusion is greatly reduced in areas of Miami-Dade and Broward counties that have low ground level elevations.

- The use of historic drought management control elevations for the selected coastal canals appears appropriate to restrict movement of the saltwater interface within the Biscayne aquifer. While this “no movement” standard may be more restrictive than the significant harm standard called for under the MFL legislation, it may be prudent to establish this as the standard until a better relationship between movement of saltwater and the lowering of canal stages or some better measurement is defined.

Based on a review of these modeling results and a review of aquifer level and water quality relationships, minimum canal operating levels are proposed for each of the District’s eleven primary water management structures (**Table 8**) to prevent saltwater intrusion.

Water Level Criteria for the Biscayne Aquifer

Selection of Minimum Canal Operational Levels to Protect the Biscayne Aquifer

Ground water levels within the Biscayne aquifer are controlled by local rainfall and by canals and structures that are regionally operated by the SFWMD. The aquifer system becomes more rainfall driven and less canal dependent as the distance from the canals increases. However from the data presented in this report, it appears that canal water levels play a major role in determining the elevation of freshwater levels in the Biscayne aquifer throughout most of South Florida. Because of this relationship, initial minimum operational levels are proposed for eleven of the District's primary coastal canals as a means to protect a major portion of the Biscayne aquifer against further saltwater intrusion. The proposed criteria consist of a minimum canal operational level and duration of the event:

- <u>Minimum Canal Operational Level</u> - The minimum water level in a canal, which, if managed for a specific period of time, is sufficient to restrict saltwater intrusion within the coastal aquifer and prevent significant harm from occurring during a period of deficient rainfall.
- <u>Duration</u> - The estimated period of time that canal water levels may remain below the minimum level without causing significant harm to coastal ground water resources.

Minimum canal operational levels are proposed for eleven primary control structures located within the LEC Planning Area. Key requirements for selecting these structures were that they must be connected to the regional system and have a sufficient canal conveyance capacity to receive water from outside of their drainage basins. The values proposed in **Table 8** represent canal operational levels necessary to protect the Biscayne aquifer and stabilize the saline interface. **Table 9** also shows water levels that are presently maintained by the District in 11 primary canals during wet, dry and average rainfall conditions.

In general, these minimum canal operational levels were derived from a review of historical stage duration curves, using values that ranged between the mean (50th percentile) and the 84th percentile (one standard deviation from the mean) for each canal, based on best professional judgement. Details of these analyses are presented in **Appendix A**.

On a regional scale, the SFWMD will manage canal levels at or above the proposed minimum operational levels specified in **Table 8** for each of the 11 principal water control structures located along the southeast coast. Water levels are managed at these levels by delivering water from the regional system. Water levels may be allowed to go below the specified level during times when water is not available to maintain the canal system or when significant rainfall has occurred that requires opening of the control structures to prevent upstream flooding. Water levels within the canals can fall below the proposed minimum operational level for a period of no more than 180 days per year. These canal levels, however, need to recover sufficiently after a drought or discharge event so that, on average, water levels will be managed at or above the specified average canal levels shown in **Table 8** on an annual basis. Actual operation of the C&SF Project canal system will be addressed in detail in the MFLs recovery and prevention section of the LEC Regional Water Supply Plan.

Table 8 also shows that operationally levels proposed for certain canals located within Broward County (C-13 and C-9) and Miami-Dade County (C-2, C-4 and C-6) will be managed at slightly higher levels during dry periods, as compared to currently proposed minimum operational levels, if sufficient water is available. The purpose of increasing these water levels is to restrict further saltwater intrusion from occurring.

Proposed Canal Operational Levels

Biscayne Aquifer Minimum Level

Water levels in the Biscayne aquifer associated with movement of the saltwater interface landward to the extent that ground water quality at the withdrawal point is insufficient to serve as a water supply source for a period of several years before recovering.

Actions Needed to Protect the Aquifer

To manage the resource to minimize the risk of the MFL being violated, the District will do the following:

1. Maintain coastal canal stages at the minimum operation levels shown in **Table 8**
2. Issue Consumptive Use Permits, consistent with the "no harm" standard.
3. Monitor Biscayne aquifer ground water levels and water quality on a regional and localized basis

4. Implement the District's water shortage program pursuant to District Rule 40E-21 F.A.C. whenever the resource is threatened or impacted by saltwater
5. Conduct further research to refine the relationships among saltwater migration, water levels in the Biscayne aquifer, and water levels in coastal canals

Implementation

The goal of the proposed canal operational levels recommended in this report is to minimize the threat of long-term movement of the saline interface in the aquifer without adversely affecting flood control. It is proposed that this be accomplished from a regional perspective by maintaining coastal canal levels during drought events at the levels specified in **Table 8.** Canal levels are seen as a surrogate measurement to indicate periods when local conditions may be favorable for saltwater intrusion. Maintenance of these levels should help prevent significant harm from occurring within the aquifer.

However, actual monitoring and implementation of water use restrictions for the LEC Planning Area will continue to be managed using the established system of ground water monitoring wells and water restriction declaration criteria. The existing network directly monitors the position of the saltwater interface within the Biscayne aquifer. Water use restriction phases are imposed when ground water levels fall near or below sea level, or when water quality tests at monitoring wells indicate that saltwater intrusion is occurring. Because this approach represents a direct measurement of the position of the saltwater interface, it is proposed these criteria continue to be used to establish water shortage restrictions for the LEC Planning Area. Additional data are needed to define the relationship between duration and frequency of low water levels in the coastal canals, the magnitude of conductivity change in the aquifer and the ability of the aquifer to recover. Strategies and methods for importing water from the regional system to maintain the canal system at the levels specified in **Table 8** will be developed as part of the Minimum Flows and Levels Recovery and Prevention Plan in the LEC Water Supply Planning process.

Surface and Ground Water Flows in South Miami-Dade County, Florida

The hydrology in south Miami-Dade County is highly complex. Historically, ground water flowed eastward and discharged into Biscayne Bay, while surface waters generally flowed southward towards the eastern Everglades, eventually reaching Florida Bay, Barnes Sound, and Card Sound. With subsequent draining of south Miami-Dade County, both surface and ground water flows to Biscayne Bay were significantly altered (Buchanan and Klein, 1976). Ground water and surface water flows toward northeastern Florida Bay also appear to have been altered, although additional work is needed to determine the extent. In addition to drainage, salinity regimes and circulation patterns in Florida Bay and Barnes Sound appear to have been modified by the construction of Flagler's Florida Keys Railroad (McIvor et al., 1994).

A secondary problem in southern Miami-Dade County is the relatively thin soil. Due to these shallow soils, canals are cut into the oolitic and bryozoan facies of the Miami Limestone and have penetrated into the Fort Thompson Formation in some areas. As a result, these canals are directly connected to some of the most permeable sections of the Biscayne aquifer. It is therefore difficult to maintain canal stages for extended periods of time without using a significant volume of water from regional storage.

For the reasons discussed above, this report will not establish MFLs for Florida Bay, Biscayne Bay, Card Sound, and Barnes Sound, located in southern Miami-Dade County. Results of this study and others show that a strong relationship exists between the position of the saltwater interface and the volume of ground water that flows into these important estuaries. However, District staff is concerned that setting a minimum level for the Biscayne aquifer in south Miami-Dade County, based solely on maintaining the existing position of the saline interface has the potential to restrict critical ground water and surface flows that move east towards Biscayne Bay and south towards Florida Bay. Setting a MFL for southern Miami-Dade County based solely on this information could result in unsatisfactory ground water and surface water flows to these estuaries. Therefore, it is recommended that the MFL for the Biscayne aquifer in southern Miami-Dade County be developed concurrently with the development of MFLs for Biscayne Bay, Florida Bay, Card Sound, and Barnes Sound.